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THE STABILITY OF PORTABLE BRIDGES CARRIED ON SLINGS BENEATH HEL--ETC(U)
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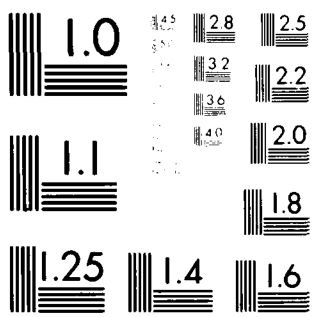

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THE STABILITY OF PORTABLE BRIDGES CARRIED ON SLINGS BENEATH HELICOPTERS

by

N. MATHESON

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SUMMARY

The Australian Armed Forces have class 16 airportable bridges in service, and there is a requirement to transport them beneath Chinook helicopters. Before the bridges can be carried as routine, it is necessary to determine the effects they have on the stability and flying qualities of the helicopter.

In this report, information available concerning the operation of helicopters carrying airportable bridges is reviewed. In addition, a series of wind tunnel tests have been made with 1/15 scale models to determine the maximum safe speed for a helicopter carrying two different class 16 bridges, a 16 m (52 ft) clear span, and a 22 m (72 ft) raft, separately on a single hook. The tests indicated that the 16 m (52 ft) bridge could be carried safely at speeds up to 65 knot on a 16 m (53 ft) cable, provided it was slung 5° nose up in the static condition, and two small flat fins were attached to the aft end. The raft had to be carried in two loads, A and B, because of weight limitations. Load A, which consisted mainly of deck boxes and accessories, could be safely carried without fins at speeds up to 60 knot on a 16 m (53 ft) cable provided it was rigged 1° to 2° nose up. Load B, which consisted of four ramps and four articulators, could also be carried at 60 knot, but small flat fins were required and it had to be slung 5° nose up and carried on a 10 m (33 ft) cable.

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16. *ABSTRACT*

The Australian Armed Forces have class 16 airportable bridges in service, and there is a requirement to transport them beneath Chinook helicopters. Before the bridges can be carried as routine, it is necessary to determine the effects they have on the stability and flying qualities of the helicopter.

In this report, information available concerning the operation of helicopters carrying airportable bridges is reviewed. In addition, a series of wind tunnel tests have been made with 1/15 scale models to determine the maximum safe speed for a helicopter carrying two different class 16 bridges, a 16 m (52 ft) clear span, and a 22 m (72 ft) raft, separately on a single hook. The tests indicated that the 16 m (52 ft) bridge could be carried safely at speeds up to 65 knot on a 16 m (53 ft) cable, provided it was slung 5° nose up in the static condition, and two small flat fins were attached to the aft end. The raft had to be carried in two loads, A and B, because of weight limitations. Load A, which consisted mainly of deck boxes and accessories, could be safely carried without fins at speeds up to 60 knot on a 16 m (53 ft) cable provided it was rigged 1° to 2° nose up. Load B, which consisted of four ramps and four articulators, could also be carried at 60 knot, but small flat fins were required and it had to be slung 5° nose up and carried on a 10 m (33 ft) cable.

CONTENTS

Accession For
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NOTATION

B = Width of bridge.
E_b = Modulus of elasticity of bridge.
E_s = Modulus of elasticity of suspension cables.
F = Force on bridge and suspension cables.
g = Acceleration due to gravity.
H = Height of bridge.
I = Moment of inertia.
I_{xx} = Moment of inertia of the bridge about its x axis.
I_{yy} = Moment of inertia of the bridge about its y axis.
I_{zz} = Moment of inertia of the bridge about its z axis.
L = Length of bridge.
l = Length scale for bridge.
l_s = Length scale for suspension cables.
n = Scale factor.
S = Sling attachment separation measured along the side of the bridge.
S_b = Structural damping factor of bridge.
S_s = Structural damping factor of suspension cables.
T = Width of bridge track.
V = Freestream velocity.
W = Weight of bridge.
α = Angle of incidence of bridge to the horizontal (positive nose up)
μ = Viscosity of fluid.
ν = Kinematic viscosity of fluid.
ρ = Density of fluid.
ρ_b = Density of bridge.
ρ_s = Density of suspension cables.
τ = Period of oscillation of bridge.
ϕ = Functional relationship.

Subscripts
m = Model.

1. INTRODUCTION

The development of modern heavy lift helicopters has made it feasible to carry large fully assembled bridge structures on slings, and to accurately position them in the field for either civil or military purposes. At the present time class 16 airportable bridges are in service with the Australian Armed Forces, and there is a requirement to transport them beneath Chinook helicopters. However, before the bridges can be carried as routine, it is necessary to determine the effects they have on the stability of the helicopter, and the speed and manoeuvring limits up to which they can be safely carried.

In this report, information available concerning the carriage of bridges on slings beneath helicopters is reviewed. The results of wind tunnel tests made at the Laboratories with 1/15 scale models to determine the stability of two class 16 airportable bridges currently being used by the Army are also given. These bridges have a different configuration from any previously tested, and it was expected that this would cause a significant difference in stability, and hence the speed at which they could be safely carried. Various slinging arrangements and stabilising techniques suitable for local conditions were also investigated.

2. THE STABILITY OF BRIDGES CARRIED ON SLINGS BENEATH HELICOPTERS —A REVIEW OF INFORMATION AVAILABLE

Full scale and model tests have previously been made to investigate the stability of class 16, medium girder (class 6), and armoured vehicle launched bridges, carried on slings beneath helicopters[1,2,3,4]. The bridges were all carried horizontally to facilitate positioning on the ground. The class 16 bridge is a fully decked single story structure made from interlocking box units which allow its length to be varied. The medium girder bridge can be either single or double story. Both it and the armoured vehicle launched bridge have twin tracks and they can be decked with detachable plates if required.

The bridges have mostly been carried on a single hook using a sling with four legs as shown in Figure 1. The weight and principal dimensions of full scale and model bridges tested previously are given in Table 1. Six different configurations have been investigated at both model and full scale. While the geometric characteristics were usually similar, the weight of the models did not always correspond with the weight of the full size bridges. This lack of similarity could lead to error in comparing the full scale results predicted from model tests with the actual results for the full size bridges. The results of these tests are reviewed in sections 2.1 to 2.5 of this report.

2.1 Stable Airspeed and Mode of Instability for Model and Full Scale Bridges

2.1.1 Model Tests

The class 16 and medium girder model bridges tested in wind tunnels adopted a broadside orientation to the flow at all forward speeds below that at which they became unstable. However, the armoured vehicle launched bridge rotated at forward speeds up to 35 knot and then developed a fore-aft oscillation which increased in amplitude as speed further increased.

The mode of instability and the speed at which it was predicted to occur for each full scale bridge are given in Table 2. A fore-aft pendulum type of oscillation usually caused by large variations in drag, and often combined with a lateral or yaw-lateral oscillation, is the predominant mode of instability for the class 16 bridges (fully decked) and the armoured vehicle launched bridge (undecked). This mode of instability also occurs for flat plate type loads which are relatively wide compared with their depth and which are suspended on relatively short cables compared with their length[5,6]. These fore-aft pendular type oscillations usually occur without warning and diverge rapidly for a small increase in speed, and are potentially very dangerous.

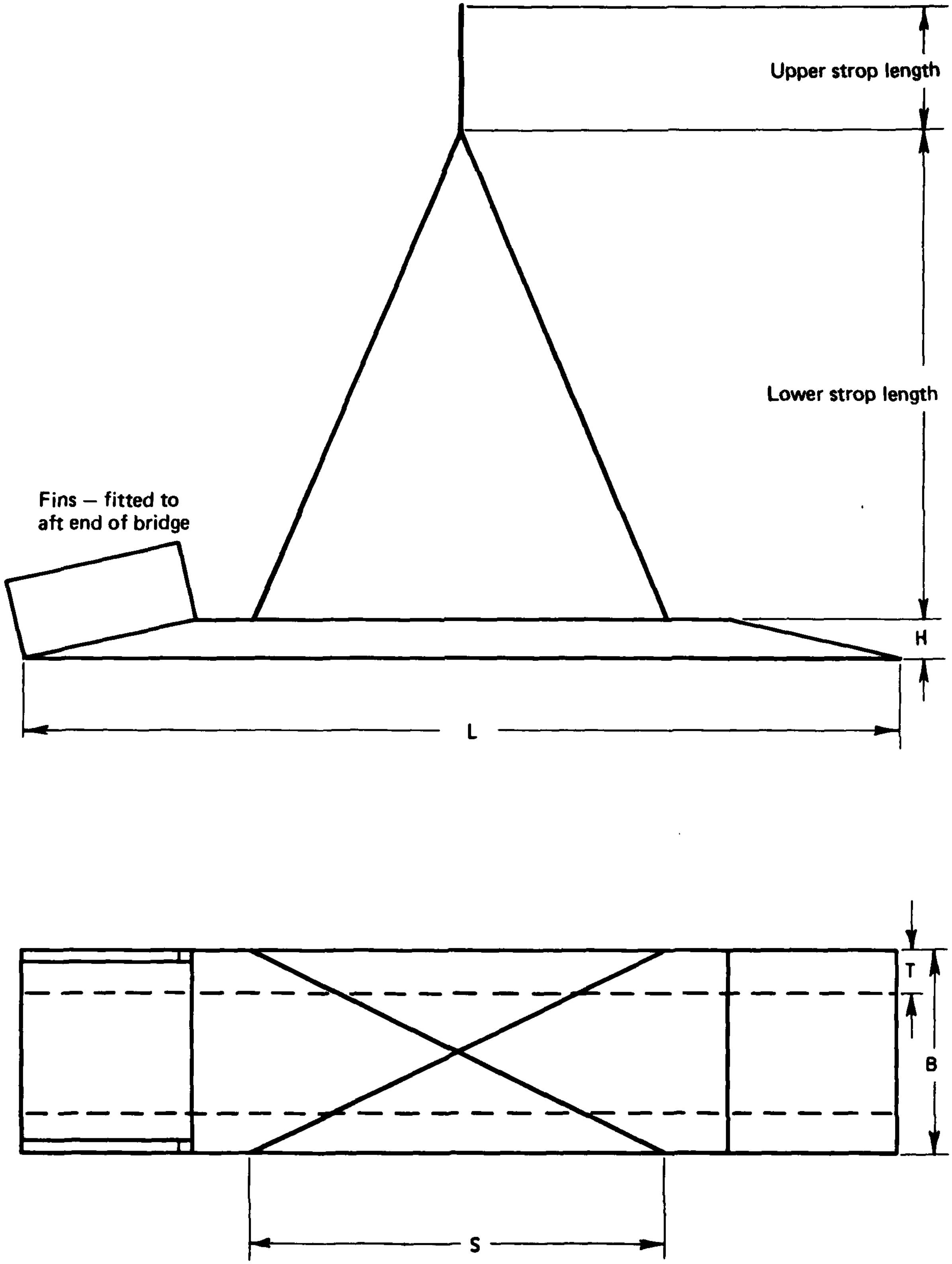


FIG 1 MODEL AND FULL SCALE BRIDGE DETAILS

TABLE 1. Model and Full Scale Bridge Data.

Type of Bridge	Actual full size bridge						Full scale data correspond. to 1/20 scale models			
	W kg (lb)	L m (ft)	B m (ft)	S m (ft)	T m (ft)	H m (ft)	W kg (lb)	L m (ft)	B m (ft)	S m (ft)
Class 16 Bridge										
9 m (28 ft) span–fully decked	1260 (2780)	8·5 (28)	3·66 (12)	3·66 (12)		0·41 (1·3)				
11 m (36 ft) span–fully decked	1900 (4170)	11·0 (36)	3·66 (12)	3·66 (12)		0·41 (1·3)	2050 (4500)	11·0 (36)	3·66 (12)	3·66 (12)
	2640 (5800)	11·0 (36)	3·66 (12)	3·66 (12)		0·41 (1·3)				
16 m (52 ft) span–fully decked	3820 (8400)	15·9 (52)	3·66 (12)	9·76 (32)		0·41 (1·3)	3500 (7700)	15·2 (50)	3·66 (12)	10·1 (33)
22 m (72 ft) span–fully decked–(Raft)	6550 (14400)	22·0 (72)	3·66 (12)	9·45 (31)			6820 (15000)	22·0 (72)	3·66 (12)	9·45 (31)
Medium Girder Bridge										
12 m (38 ft) span–single story–decked							3820 (8400)	11·6 (38)	4·27 (14)	11·6 (38)
17 m (55 ft) span–single story–decked							7000 (15400)	16·8 (55)	4·27 (14)	7·93 (26)
9 m (28 ft) span–single story–undecked	650 (1420)	8·5 (28)	4·27 (14)	4·27 (14)	0·7 (2·3)	0·58 (1·9)				
12 m (38 ft) span–single story–undecked	2950 (6500)	11·6 (38)	4·27 (14)	8·08 (26·5)	0·7 (2·3)	0·58 (1·9)				
13 m (42 ft) span–single story–undecked	970 (2130)	12·8 (42)	4·27 (14)	4·27 (14)	0·7 (2·3)	0·58 (1·9)				
17 m (55 ft) span–single story–undecked	4000 (8800)	16·8 (55)	4·27 (14)	8·08 (26·5)	0·7 (2·3)	0·58 (1·9)				
17 m (56 ft) span–single story–undecked	1270 (2800)	17·1 (56)	4·27 (14)	6·10 (20)	0·7 (2·3)	0·58 (1·9)				
24 m (80 ft) span–single story–undecked	5320 (11700)	24·4 (80)	4·27 (14)	13·3 (43·5)	0·7 (2·3)		4950 (10900)	24·4 (80)	4·27 (14)	13·4 (44)
17 m (55 ft) span–double story–undecked	7000 (15400)	16·8 (55)	4·27 (14)	7·93 (26)	0·7 (2·3)		6450 (14200)	16·8 (55)	4·27 (14)	7·93 (26)
Armoured Vehicle Launched Bridge										
16 m (52 ft) span–single story–undecked	7140 (15700)	15·9 (52)	4·27 (14)				7180 (15800)	15·9 (52)	4·27 (14)	

TABLE 2

Maximum Stable Forward Speed and Mode of Instability for Full Size Bridge Structures Predicted from Wind Tunnel Tests of 1/20 Scale Models[1,3].

Upper strop length m (ft)	Lower sling height m (ft)	Stable speed (knot)	Mode of instability and general comments
11 m (36 ft) Class 16 Airportable Bridge—Decked			
1·5 (5)	6·1 (20)	60	Fore-aft pendulum oscillation—induced from low speed. Bridge remained broadside at all times.
1·5 (5)	12·2 (40)	> 100	
1·5 (5)	18·3 (60)	> 100	
6·1 (20)	6·1 (20)	75	High frequency flutter below 65 kn. Unstable combined lateral and fore-aft pendulum oscillation at 75 knot. Bridge remained broadside at all times.
6·1 (20)	12·2 (40)	90	Unstable combined lateral and fore-aft pendulum oscillation at 90 knot. Bridge remained broadside at all times.
12·2 (40)	6·1 (20)	75	High frequency flutter between 50 and 75 knot. Unstable combined lateral and fore-aft pendulum oscillation at 75 knot. Bridge remained broadside at all times.
15 m (50 ft) Class 16 Airportable Bridge—Decked			
0	6·1 (20)	40	Large fore and aft pendular oscillation below 40 kn. At 60 knot bridge lifted and front legs went slack.
1·5 (5)	6·1 (20)	40	"as above"
1·5 (5)	12·2 (40)	> 100	
1·5 (5)	18·3 (60)	85	Small combined yaw-lateral oscillation at 85 knot, became negligible at speeds greater than 100 knot.
6·1 (20)	6·1 (20)	65	Small amplitude flutter at 65 knot. Unstable combined lateral and fore-aft oscillation above 65 knot.
6·1 (20)	12·2 (40)	85	Small yaw-lateral pendulum oscillation at 85 knot, became negligible for speeds greater than 100 knot.
12·2 (40)	6·1 (20)	60	Small amplitude flutter from 50 to 75 kn. Unstable combined lateral and fore-aft oscillation above 95 knot.
22 m (72 ft) Class 16 Airportable Bridge (Raft)—Decked			
1·5 (5)	6·1 (20)	60	No preferred position below 40 knot. ±30° yaw from 40 to 60 knot. Unstable fore-aft oscillation at 70 knot.
1·5 (5)	12·2 (40)	70	"as above" except became unstable at 80 knot.
1·5 (5)	18·3 (60)	70	"as above".
6·1 (20)	6·1 (20)	70	"as above".
6·1 (20)	12·2 (40)	70	"as above".
12·2 (40)	6·1 (20)	70	"as above".

TABLE 2.—Continued

Upper strop length m (ft)	Lower sling height m (ft)	Stable speed (knot)	Mode of instability and general comments
12 m (38 ft) Medium Girder Bridge—Single Story—Decked			
1·5 (5)	6·1 (20)	60	±40° yaw oscillation up to 30 knot, changes to a fore-aft pendular oscillation with front legs becoming slack at 65 knot.
1·5 (5)	12·2 (40)	60	"as above".
1·5 (5)	18·3 (60)	60	"as above".
6·1 (20)	6·1 (20)	60	"as above".
6·1 (20)	12·2 (40)	60	"as above".
12·2 (40)	6·1 (20)	60	"as above".
17 m (55 ft) Medium Girder Bridge—Single Story—Decked			
1·5 (5)	6·1 (20)	20	±20° yaw at 20 knot, increased to ±60° at 50 knot. Occasional spin about attachment point above 50 knot.
1·5 (5)	12·2 (40)	20	"as above"—front strops tending to become slack above 50 knot.
1·5 (5)	18·3 (60)	20	"as above".
6·1 (20)	6·1 (20)	20	"as above".
6·1 (20)	12·2 (40)	20	"as above".
12·2 (40)	6·1 (20)	20	"as above".
24 m (80 ft) Medium Girder Bridge—Single Story—Undecked			
1·5 (5)	6·1 (20)	> 100	Small amplitude pitching from 35 to 45 knot, small lateral pendulum oscillation from 45 to 55 knot.
1·5 (5)	12·2 (40)	> 100	
1·5 (5)	18·3 (60)	90	Irregular motion.
6·1 (20)	6·1 (20)	90	Small amplitude flutter from 35 to 50 knot.
6·1 (20)	12·2 (40)	90	"as above".
12·2 (40)	6·1 (20)	90	"as above".
17 m (55 ft) Medium Girder Bridge—Double Story—Undecked			
1·5 (5)	6·1 (20)	30	±30° yaw at 30 knot. Small yaw-lateral oscillation, with increasing yaw above 60 knot.
1·5 (5)	12·2 (40)	25	±40° yaw at 25 knot. Combined yaw-lateral oscillation at higher speed.
1·5 (5)	18·3 (60)	25	±20° yaw at 25 knot. Large amplitude yaw-lateral oscillation above 70 knot.
6·1 (20)	6·1 (20)	25	"as above".
6·1 (20)	12·2 (40)	25	"as above".
12·2 (40)	6·1 (20)	25	"as above".

TABLE 2.—Continued

Upper strop length m (ft)	Lower sling height m (ft)	Stable speed (knot)	Mode of instability and general comments
			16 m (52 ft) Armoured Vehicle Launched Bridge—Undecked
1·8 (6)	not known	<60	Load rotated continously at forward speed up to 35 knot where a fore-aft swing was initiated which increased in amplitude with speed.

A yaw or combined yaw-lateral oscillation is the main mode of instability found for the long decked single story and undecked double story medium girder bridges. This type of instability is very severe and the predicted stable full scale speed is below 30 knot. However, the undecked single story medium girder bridge is very stable and it could be carried at up to 90 knot.

Increasing the length of either the upper strop, or the lower sling, sometimes allows the bridges to be carried at slightly higher speeds, but in most cases the maximum speed and mode of instability is not influenced by the length of the cable.

2.1.2 Full Scale Tests

The maximum speed and mode of instability determined from tests of various full scale bridges carried beneath a Sea King helicopter are listed in Table 3. The bridges were rigged so that they were horizontal in hover. For the trials the ramps on the class 16 bridges were partially replaced with plywood to keep the weight within the load capacity of the Sea King. Consequently, the results in Table 3 do not represent normal class 16 bridges.

In all cases, the bridges flew in a broadside position, and large drag and negative lift forces were produced at quite moderate forward speeds. Since this speed often corresponded with the minimum power speed, the helicopter became very difficult to handle and it could be easily overloaded inadvertently, especially when the bridges were carried on the 8·2 m (27 ft) and 13·4 m (44 ft) cables. On the longer 20·4 m (67 ft) cable the bridges were not quite as stable, and the speed was limited by lateral oscillation. Provided adequate care was taken most of the bridges could be carried safely at speads of 30 to 40 knot.

The speed of 30 to 40 knot at which the full scale bridges could be carried safely was much lower than the speed at which instability had been predicted from model tests. This is because the effects of various manoeuvres, particularly ascents and descents, which adversely affect the performance and handling of the helicopter, could not be directly taken into account in the model tests. In addition, in the full scale flight tests, the bridges cannot be allowed to become unstable because they may cause the helicopter to become uncontrollable. Therefore, for safety, the speed up to which the bridges can be tested at full scale is lower than the speed at which they are anticipated to become unstable from the model tests. Nevertheless, there still appears to be some discrepancy between the full scale and model results for the 20·4 m (67 ft) cable. This could be caused by scale effects since the bridge is a relatively 'streamlined' body and viscous effects may be important.

It was found that the bridges rotated during prolonged hovering. There was no preferred direction of rotation, and the shorter bridges were more prone to this form of motion than the longer ones. However, it was not a problem provided reasonably quick departures and set downs were made, and the bridges became aligned broadside to the airstream at reasonably low forward speeds.

2.2 Limiting Speed and Mode of Instability for Model and Full Scale Bridges Fitted with Stabilising Fins

Full scale and model tests have been carried out with stabilising fins fitted to class 16 air-

TABLE 3

Maximum Forward Speed and Mode of Instability for Full Scale Bridges Carried under a Sea King Helicopter[4].

Upper strop length m (ft)	Lower sling height m (ft)	Max. speed achieved (knot)	Weight kg (lb)	Mode of oscillation and general comments
(a) *9 m (28 ft) Class 16 Airportable Bridge—Decked*				
0·3 (1)	6·1 (20)	50	1300 (2870)	Excessive load at 50 knot, tendency to develop a lateral swing.
2·1 (7)	6·1 (20)	50	1250 (2750)	Excessive load of 50 knot, tendency to develop a lateral swing.
(b) *11 m (36 ft) Class 16 Airportable Bridge—Decked*				
1·8 (6)	6·4 (21)	0	1890 (4150)	Excessive load in hover.
7·0 (23)	6·4 (21)	0	1900 (4170)	Excessive load in hover.
14·0 (46)	6·4 (21)	45	1900 (4190)	Lateral oscillation and excessive load.
(c) *9 m (28 ft) Medium Girder Bridge—Single Story—Undecked*				
2·1 (7)	6·1 (20)	70	630 (1390)	Excessive transmission oil temperature.
7·3 (24)	6·1 (20)	45	650 (1420)	Lateral oscillation (aircraft rolling through $\pm5°$).
14·3 (47)	6·1 (20)	45	650 (1434)	Lateral oscillation (aircraft rolling through $\pm5°$).
(d) *13 m (42 ft) Medium Girder Bridge—Single Story—Undecked*				
1·8 (6)	6·4 (21)	60	970 (2130)	Excessive transmission oil temperature.
(e) *17 m (56 ft) Medium Girder Bridge—Single Story—Undecked*				
0·3 (1)	6·1 (20)	48	1030 (2270)	Excessive load and high transmission oil temperature.
2·1 (7)	6·1 (20)	48	1030 (2270)	(as above).
14·3 (47)	6·1 (20)	40	1280 (2820)	Lateral oscillation.
NOTE: Bridges all adopted a broadside position from low forward speed				

portable bridges, medium girder bridges, and an armoured vehicle launched bridge[1,2,3]. Two fins were always fitted, one each side at the aft end of each bridge. The span of the fins was normal to the deck and the chord parallel to the longitudinal axis of the bridge. With the bridge slung in an approximately horizontal attitude the longitudinal axis was then constrained by the aerodynamic forces on the fins to remain in the vertical plane of flight. With this orientation the aerodynamic forces acting on the bridge are much smaller than when it is in the stable broadside position without fins. This improves the handling qualities of the helicopter and prevents it from becoming so easily overloaded, and also allows the bridge to be carried at a higher forward speed.

2.2.1 Model Tests

Wind tunnel tests with models of the bridges listed in Table 1 and fitted with fins, indicate

that the size of the fins has a significant effect on the mode of instability and a small effect on the maximum speed at which they could be carried. If the fins were very large, the trail angle also became large, and a severe fore-aft oscillation developed which often increased in amplitude suddenly and without warning. In a real situation this could be disastrous as the bridge could strike the tail of the helicopter.

When the fins were made smaller so that the bridges were just directionally stable, either a steady state yaw, or a combined yaw-lateral pendulum mode of instability developed, which gradually increased in amplitude as the speed increased. Although, this occurred at a slightly lower speed than the trail angle divergence instability produced with the larger fins, it permitted a small increase in carrying speed compared with the bridges without fins. The reduced stability with smaller fins is preferable because a 'safe' mode of instability is established which does not develop abruptly, and the pilot can slow down in time to stop the oscillation from diverging. The quickly diverging fore-aft oscillation, which had occurred without fins and with the large fins, was not expected to cause any trouble when the full size bridges were fitted with the geometrically scaled smaller 'optimum' size fins, provided sudden accelerations and decelerations were avoided.

The size of the recommended fins determined from the wind tunnel tests, and the predicted speed and mode of instability for the bridges with different sling heights and initial 'hover' angles of incidence are given in Table 4.

Comparison of corresponding results in Table 2 and 4 indicates that most of the bridges can be carried at a slightly higher forward speed when fins are fitted. The single story decked, and double story undecked medium girder bridges are notable exceptions where the stable speed is substantially increased from about 20 knot to 100 knot. In these two cases, the fins are ideal for increasing the very low yaw-stability which caused the bridges to become unstable at low speed.

The model tests indicate that the 'optimum' size of the fins given in Table 4 for the 15 m (50 ft) decked class 16 bridge is rather critical because a 0·13 m (0·4 ft) increase in fin height reduced the stable speed by about 5 knot. For the 22 m (72 ft) raft, the yaw-lateral pendulum mode of instability occurred at only a slightly lower speed than a sudden backswing of the bridge to the tail of the helicopter, and the stable speed limits indicated must not be exceeded. Similarly, if the speed of either the 24 m (80 ft) undecked or the 12 m (38 ft) decked single story medium girder bridge is slightly above the speed given in Table 4, it turns broadside and becomes violently unstable.

2.2.2 Full Scale Tests

The speed and mode of instability for the full scale bridges tested are listed in Table 5. Each bridge was fitted with the 'optimum' size fin given previously in Table 4. These tests were made with two different helicopters: a CH47A Chinook, and a CH54A Skycrane. At the same speed the amplitude of load oscillation was not as large with the CH54A mainly because the load was attached closer to the centre of gravity of the helicopter. This caused a smaller disturbing moment to be applied by the swinging load and consequently the bridges could be carried at slightly higher speeds with the CH54A, as shown in Table 5. Bearing this in mind, the maximum speeds predicted from the wind tunnel tests, given in Table 4, are in reasonable agreement with the full scale results. However, the yaw or combined yaw-lateral pendulum mode of instability predicted from the wind tunnel tests did not usually occur, and the maximum speed was mostly limited by a trail angle instability, or a fore and aft pendulum oscillation which occurred about a large trail angle. This difference is probably caused by scale effects, and lack of representation of helicopter and bridge manoeuvring in the model tests.

Initial tests with the CH47A carrying the 11 m (36 ft) class 16 bridge indicated that a fore and aft oscillation limited the speed to 65 knot. However, during a descent, the speed was inadvertently allowed to rise to 70 knot and the fore and aft oscillation diverged rapidly and the bridge had to be jettisoned. In view of this incident, the full scale bridges were re-tested with slightly larger fins to increase their directional stability. The size of these fins, compared with the size of the fins originally recommended from the wind tunnel tests, are given in Table 6. The fore-aft oscillation was reduced slightly, but the airspeed and mode of instability was not changed significantly. This is contrary to the results from the wind tunnel tests, and it seems

TABLE 4

Maximum Stable Forward Speed, Mode of Instability, and 'Optimum' Fin Size for Full Scale Bridges, Predicted from Wind Tunnel Tests of 1/20 Scale Models[1,3].

Lower sling height m (ft)	Bridge incidence (+ve nose up)	Stable speed (knot)	Mode of instability
11 m (36 ft) Class 16 Airportable Bridge—Decked Fins—two fins, each 0·76 m (2·5 ft) chord × 0·85 m (2·8 ft) high			
6·1 (20)	0	60	Yaw-lateral pendulum oscillation
6·1 (20)	+5°	80	,,
9·2 (30)	0	70	,,
9·2 (30)	+5°	90	,,
15·2 (50)	0	70	,,
15·2 (50)	+5°	80	,,
15 m (50 ft) Class 16 Airportable Bridge—Decked Fins—two fins, each 1·07 m (3·5 ft) chord × 0·89 m (2·9 ft) high			
4·6 (15)	0	55	Yaw-lateral pendulum oscillation
4·6 (15)	+5°	75	,,
10·7 (35)	0	80	,,
10·7 (35)	+5°	105	,,
16·8 (55)	0	90	,,
16·8 (55)	+5°	110	,,
22 m (72 ft) Class 16 Airportable Bridge (Raft)—Decked Fins—two fins, each 1·52 m (5·0 ft) chord × 1·16 m (3·8 ft) high			
4·6 (15)	0	60	Yaw-lateral pendulum oscillation
4·6 (15)	+5°	80	,,
10·7 (35)	0	80	,,
10·7 (35)	+5°	105	,,
16·8 (55)	0	90	,,
16·8 (55)	+5°	120	,,
12 m (38 ft) Medium Girder Bridge—Single Story—Decked Fins—two fins, each 1·52 m (5·0 ft) chord × 1·02 m (3·3 ft) high			
4·6 (15)	0	65	Yaw divergence
4·6 (15)	+5°	80	,,
10·7 (35)	0	75	,,
10·7 (35)	+5°	95	,,
16·8 (55)	0	85	,,
16·8 (55)	+5°	105	,,
17 m (55 ft) Medium Girder Bridge—Single Story—Decked Fins—two fins, each 1·52 m (5·0 ft) chord × 1·27 m (4·2 ft) high			
6·1 (20)	0	80	Yaw divergence
6·1 (20)	+5°	100	,,
13·7 (45)	0	95	,,
13·7 (45)	+5°	110	,,
18·3 (60)	0	100	,,
18·3 (60)	+5°	125	,,

TABLE 4.—Continued

Lower sling height m (ft)	Bridge incidence (+ve nose up)	Stable speed (knot)	Mode of instability
Fins—two fins, each 1·52 m (5·0 ft) chord × 1·78 m (5·8 ft) high			
6·1 (20)	0	95	Yaw divergence
6·1 (20)	+5°	110	,,
13·7 (45)	0	110	Yaw-lateral pendulum oscillation
13·7 (45)	+5°	85	,,
18·3 (60)	0	80	,,
18·3 (60)	+5°	70	,,
24 m (80 ft) Medium Girder Bridge—Single Story—Undecked *Fins*—two fins, each 1·52 m (5·0 ft) chord × 1·78 m (5·8 ft) high			
4·6 (15)	0	90	Yaw divergence
4·6 (15)	+5°	105	,,
10·7 (35)	0	100	,,
10·7 (35)	+5°	115	,,
16·8 (55)	0	105	,,
16·8 (55)	+5°	120	,,
17 m (55 ft) Medium Girder Bridge—Double Story—Undecked *Fins*—two fins, each 1·52 m (5·0 ft) chord × 1·78 m (5·8 ft) high			
4·6 (15)	0	130	Yaw-lateral pendulum oscillation
6·1 (20)	0	140	,,
9·2 (30)	0	150	,,
16 m (52 ft) Armoured Vehicle Launched Bridge *Fins* (a) two fins, each 1·52 m (5·0 ft) chord × 1·22 m (4·0 ft) high			
9·1 (30)	0	Unstable	
12·2 (40)	0	Unstable	
(b) two fins, each 1·37 m (4·5 ft) chord × 2·29 m (7·5 ft) high			
9·1 (30)	0	98	Yaw oscillation above 80 knot.
12·2 (40)	0	83	Yaw oscillation
(c) two fins, each 1·37 m (4·5 ft) chord × 2·49 m (8·2 ft) high			
9·1 (30)	0	93	
12·2 (40)	0	100	
18·3 (60)	0	65	Yaw-lateral oscillation
(d) two fins, each 1·22 m (4·0 ft) chord × 2·59 m (8·5 ft) high			
9·1 (30)	0	93	
12·2 (40)	0	101	

TABLE 5

Maximum Forward Speed and Mode of Oscillation for Full Size Bridges Fitted with Stabilizing Fins[2].

Upper strop length m (ft)	Lower sling height m (ft)	Max. speed achieved (knot)	Mode of oscillation and general comments
(1) CH47A CHINOOK HELICOPTER			
11 m (36 ft) Class 16 Airportable Bridge—Decked—2640 kg (5800 lb)			
9·5 (31)	4·6 (15)	50	Speed limited by fore-aft swing.
4·6 (15)	9·2 (30)	70	Bridge developed violent fore-aft swing at 70 kn during a descent and had to be jettisoned.
12 m (38 ft) Medium Girder Bridge—Single Story—Undecked—2910 kg (6400 lb)			
4·6 (15)	9·2 (30)	55	Behaviour satisfactory at 55 knot, but pilots reluctant to fly faster.
17 m (55 ft) Medium Girder Bridge—Single Story—Undecked—4000 kg (8800 lb)			
1·5 (5)	7·6 (25)	40	Fore-aft swing, and bridge came close to helicopter.
4·6 (15)	9·2 (30)	65	Fore-aft swing, but behaviour acceptable.
4·6 (15)	13·7 (45)	65	Pilots disliked this long suspension for hover manoeuvres.
(2) CH54A SKYCRANE HELICOPTER			
16 m (52 ft) Class 16 Airportable Bridge—Decked—3820 kg (8400 lb)			
1·5 (5)	6·1 (20)	70	While turning at 70 knot bridge trailed to 30° incidence with a load in the hook of 9100 kg (20,000 lb). Bridge remained steady in straight forward flight up to 70 knot.
4·6 (15)	9·2 (30)	75	Lateral oscillation limited speed.
9·2 (30)	9·2 (30)	70	Fore and aft swing limited speed.
1·5 (5)	16·8 (55)	60	Handling not as good as with shorter cables.
22 m (72 ft) Class 16 Airportable Bridge (Raft)—Decked 8550 kg (14,400 lb)			
4·6 (15)	9·2 (30)	50	Bridge structural failures occurred twice.
17 m (55 ft) Medium Girder Bridge—Single Story—Undecked—4000 kg (8800 lb)			
4·6 (15)	9·2 (30)	80	Lateral oscillation in descents.
24 m (80 ft) Medium Girder Bridge—Single Story—Undecked—5320 kg (11,700 lb)			
4·6 (15)	9·2 (30)	80	Fore-aft swing occurs at 80 knot.
17 m (55 ft) Medium Girder Bridge—Double Story—Undecked—7000 kg (15,400 lb)			
4·6 (15)	9·2 (30)	80	Stable up to 80 knot.

TABLE 6

Size of Fins Recomemnded for the Full Scale Bridges[2].

Bridge	Original 'Optimized' Fins		Large Fins	
	Chord m (ft)	Height m (ft)	Chord m (ft)	Height m (ft)
Class 16 Airportable Bridge				
11 m (36 ft) span—decked	0·76 (2·5)	0·85 (2·8)	1·52 (5·0)	1·22 (4·0)
13 m (44 ft) span—decked	0·91 (3·0)	0·85 (2·8)	1·52 (5·0)	1·22 (4·0)
16 m (52 ft) span—decked	1·07 (3·5)	0·91 (3·0)	1·52 (5·0)	1·22 (4·0)
22 m (72 ft) span (Raft)—decked	1·52 (5·0)	1·16 (3·8)	1·52 (5·0)	1·83 (6·0)
Medium Girder Bridge				
12 m (38 ft) span—single story—undecked	1·52 (5·0)	1·01 (3·3)	1·52 (5·0)	1·22 (4·0)
17 m (55 ft) span—single story—undecked	1·52 (5·0)	1·28 (4·2)	1·52 (5·0)	1·83 (6·0)
24 m (80 ft) span—single story—undecked	1·52 (5·0)	1·78 (5·8)	1·52 (5·0)	1·83 (6·0)
17 m (55 ft) span—double story—undecked	1·52 (5·0)	1·78 (5·8)	1·52 (5·0)	1·83 (6·0)
Armoured Vehicle Launched Bridge				
16 m (52 ft) span—undecked	1·22 (4·0) (minimum)	2·44 (8·0) (minimum)		

that the size of the fins is not as critical in determining the mode of oscillation as the model tests indicated.

It was considered that the helicopters could not be flown safely on a routine mission at the maximum speeds given in Table 5. These are the speeds at which the bridges just become unstable and some margin is necessary to allow for manoeuvring and unforeseen circumstances which might occur. The maximum speeds recommended for carrying the bridges safely are given in Table 7, and are therefore below the limiting speeds. Even at these relatively low speeds, the helicopter must still be manoeuvred carefully at all times, (3 m/s (600 ft/min) maximum rate of climb or descent; 10° maximum angle of bank; 5° to 7° maximum approach angle).

2.2.3 Effect of Changes in the Length of the Suspension Cable

The model tests indicate that variations in the upper strop length from 0 to 12 m (40 ft) would not affect the speed or mode of oscillation for any of the bridges. However, an increase in the lower sling height from 6 m (20 ft) to 18 m (60 ft) usually increased the maximum stable speed by about 20 knot. Exceptions were the 17 m (55 ft) single story decked medium girder bridge fitted with large fins, and the armoured vehicle launched bridge, where increasing the lower sling height from 12 m (40 ft) to 18 m (60 ft) reduced the stable speed by 40 knot. Results for variations in both the upper strop length, and lower sling height are given in Table 4.

Full scale tests indicate that a 14 m (45 ft) separation between the helicopter and bridge gives the most satisfactory compromise between a long cable for increased clearance, and a short cable for which the pilots considered the flying qualities were marginally improved[2]. The pilots of both helicopters preferred the shorter suspension systems, and, contrary to wind tunnel predictions, increases in lower sling height were not judged to improve stability.

TABLE 7
Maximum Recommended Service Speed for Helicopters Carrying Airportable Bridges Fitted with Stabilizing Fins.

Bridge	Maximum recommended speed (knot) Helicopter CH47A	 CH54A
Class 16, and medium girder bridge—decked	45	55
Medium girder bridge—undecked.	60	80

2.2.4 Effect of Bridge Attitude

The model tests show that the maximum stable airspeed could be increased by up to 20 knot if the bridges were rigged 5° nose up instead of horizontally in hover. Typical results are given in Table 4. However, directional stability was reduced for speeds below about 30 knot, and yaw displacements of up to $\pm 10°$ were experienced. To avoid a further reduction in directional stability, nose up attitudes greater than 5° were not recommended.

Full scale tests were carried out on class 16 bridges with a 5° nose up attitude but contrary to the model tests there was no significant difference in the speed at which the bridge could be carried. However, as predicted from the model tests, the bridges were not as stable directionally as those rigged horizontally, and this was particularly noticeable in forward flight with a relatively high rate of descent.

2.2.5 Forces on the Suspension Hook

The forces acting on the suspension hook have been measured for models both with and without stabilizing fins[1]. The tests were made with the bridges statically rigged at zero degrees of incidence. Typical results for the vertical force (including the weight of the bridge) and the drag force on the hook, scaled to the full size bridge in an 80 knot airstream, are given in Table 8. These results show that fitting fins to align the bridges with their longitudinal axis parallel to the direction of flight, reduces the aerodynamic component of the vertical force, and the drag force, by an average of about 80% and 65% respectively. It should be noted that downwash effects are not included in these results.

Full scale tests have confirmed that fins align the bridges with the direction of the airstream and substantially reduce the force on the hook in both level flight and during manoeuvres[2]. For example, a 16 m (52 ft) class 16 bridge without fins exerted a greater force on the hook at 40 knot than it did with fins at 70 knot. The force on the hook can also be much greater than the static weight of the bridge. For example, during trials of a bridge weighing 3860 kg (8500 lb), hook loads of up to 9100 kg (20 000 lb) were measured during a left turn at 60 knot where the load trailed at an angle of 31° to the vertical. Loads on the hook of twice the static weight of the bridge were common during manoeuvres, and occasionally forces of up to three times the static weight were measured.

Large fluctuations in the load on the hook have also been found in full scale tests[2]. In most cases the load on the hook varied cyclically with the load oscillation. The fatigue implications on the helicopter and load suspension system, and on the load itself, should be considered when planning bridge-carrying missions. The raft tested by Bradley and Toms[2] at full scale failed twice because of fatigue effects.

When carrying a bridge, a device to show the force exerted on the helicopter by the load (load indicator) should be incorporated in the suspension system. This indicator would show variations in the force on the hook during manoeuvres, the force produced by the rotor down-

TABLE 8

Vertical Force and Drag Force on the Suspension Hook for Full Size Bridges Rigged Horizontally with a 7·6 m (25 ft) Lower Sling Height in an 80 Knot Airstream, Predicted from Model Tests in a Wind Tunnel.

(Note: rotor downwash effects are not included).

Bridge	Static weight kg (lb)		Vertical force on hook kg (lb)		Vertical force on hook for bridges with fins as a % of vertical force for bridges without fins	Drag on hook kg (lb)		Drag on hook for bridges with fins as a % of drag for bridges without fins
	Without fins	With fins	Without fins	With fins		Without fins	With fins	
11 m (36 ft) Class 16	Not tested							
15 m (50 ft) Class 16	3500 (7700)	3650 (8000)	5000 (11000)	3800 (8400)	76%	1300 (2900)	270 (600)	21%
22 m (72 ft) Class 16 (Raft)	6800 (15000)	7000 (15400)	9250 (20400)	7550 (16600)	81%	1650 (3600)	730 (1600)	44%
12 m (38 ft) MGB Single story—decked	3800 (8400)	3950 (8700)	5000 (11000)	4300 (9500)	86%	1100 (2400)	500 (1100)	46%
17 m (55 ft) MGB Single story—decked	6950 (15300)	—	7750 (17100) (Result at 70 knot)	7200 (15800)	93%	910 (2000)	360 (800)	40%
24 m (80 ft) MGB Single story—undecked	4950 (10900)	5150 (11300)	6550 (14400)	5250 (11600)	80%	4100 (9000)	500 (1100)	12%
17 m (55 ft) MGB Double story—undecked	6450 (14200)	6550 (14400)	7000 (15400)	6700 (14700)	96%	3450 (7600)	1000 (2200)	29%

wash, and fluctuating forces induced when the load oscillates. The pilot can then monitor the effective load on the helicopter from the cockpit and restrict his flying accordingly.

2.3 Rotor Downwash Effects

Full scale tests have shown that the vertical downward force on the bridge created by the rotor downwash can substantially reduce the hovering performance of the helicopter[2,4]. For example, a 5270 kg (11,600 lb) load was exerted on the hook when a 16 m (52 ft) span class 16 bridge weighing 3840 kg (8450 lb) was suspended from a CH54A in hover. In general, full scale tests have shown that at speeds up to 10 knot the rotor downwash induces an average pressure on the bridge of about 0·29 kPa (6 psf), although in some circumstances pressures up to 0·48 kPa (10 psf) have been found.

At a transition speed of around 15 to 20 knot the induced vertical drag is almost zero because the downwash is deflected aft of the bridge. The greater the distance between the helicopter and load the lower the airspeed at which the vertical drag reduces to zero. Slightly lower bridge loadings occur with longer suspension cables because of the spread of the downwash.

Although the vertical drag was usually highest with the span crosswise to the axis of the helicopter it was not greatly influenced by the horizontal orientation of the bridge[2,4]. In addition, despite lower disc loading of the tandem rotor CH47A compared with the single rotor CH54A, the vertical drag was slightly greater when the bridges were carried with the tandem rotor helicopter.

The effective nett lift loss caused by the downwash must be allowed for when planning a mission. It is recommended that a uniform pressure of 0·29 kPa (6 psf) be used to estimate this lift loss unless more accurate data are available. If a 'load on the hook indicator' is built into the suspension system, then the vertical drag and manoeuvring forces can be monitored to ensure that the helicopter does not become overloaded.

2.4 Two Point Load Suspension

One of the simplest and most effective methods for increasing the stability of a slung load is to restrict its motion in yaw by attaching it to the helicopter at two points instead of one[5,7,8]. In general tandem or longitudinally displaced attachment points or hooks are the most practicable. By using two hooks most loads can be carried safely at speeds well over 100 knot which is sometimes above the power limiting speed of the helicopter.

Pryor and Sheldon have shown that a 16 m (52 ft) long armoured vehicle launched bridge fitted with fins would become unstable at about 90 knot on a single hook. The same bridge without fins had a stable speed of 130 knot when carried on two cables 9·1 m (30 ft) long and 4·6 m (15 ft) apart[3]. Even higher speeds were achieved with shorter cables where the yaw restraint is greater. Similar increases in stable airspeed have been obtained for flat plate type loads similar to class 16 airportable bridges[5]. Two point load suspension systems also offer the advantage of increased azimuth control permitting more precise load orientation at touchdown.

2.5 Position of the Centre of Gravity and Centre of Pressure

Placing the centre of gravity of the bridge as far forward as possible, preferably in front of the centre of pressure where the load becomes directionally stable, increases stability and allows the bridge to be carried at higher speeds[8]. Unfortunately, with bridges, it is usually not practical to alter the position of the centre of gravity in relation to the centre of pressure. Nevertheless, consideration should be given to placing the centre of gravity in a forward position with respect to the centre of pressure during the rigging procedure.

3. MODEL—FULL SIZE BRIDGE SCALING PARAMETERS

The stability of a bridge carried on a sling beneath a helicopter can be investigated experimentally by testing a model in a wind tunnel. This offers a simple and direct means of identifying which type of instability limits a given configuration, as well as the speed and other conditions under which this is likely to occur. Ideas for suppressing instabilities, or for increasing manoeuvrability can also be investigated easily. Model testing has the additional advantage of not being limited by the performance of the helicopter, the configuration of the bridge, or the sling attachment geometries available. In addition, compared with full scale testing, it does not endanger personnel or risk damage to expensive equipment. In this section, the scaling parameter requirements and precautions necessary in using models to predict the behaviour of a full scale bridge carried on a sling beneath a helicopter are reviewed.

The principal variables which can affect the motion of a bridge suspended on thin cables from a hook and free to oscillate in a fluid in motion are given in Equation 1.

$$F = \phi_1 \{V, l, \rho, g, \mu, \rho_s, \rho_b, E_s, E_b, S_b, S_s\} \qquad 1$$

Separate variables have been included for the material of the bridge and suspension cables because they are often different. The slings are usually either nylon webbing or wire rope, and the bridges are mostly steel.

Using dimensional arguments, Equation 1 can be written in a non-dimensionalized parametric form given by Equation 2.

$$F/(\rho V^2 l^2) = \phi_2 [V^2/(gl),\ \rho V l/\mu,\ \rho_b/\rho,\ E_t/(\rho V^2),\ E_s/(\rho V^2),\ S_b,\ S_s] \qquad 2$$

Observations and measurements at model scale can only be extrapolated to full scale provided the correct relationship is maintained between each scaling parameter in Equation 2. This will ensure that the relative magnitude of the gravitational, inertial, aerodynamic, elastic, and structural damping forces, and the amplitude and frequency of oscillation, is maintained between the model and full size bridge. Unfortunately, scaling of all the variables is not always compatible, and relaxation of one or more of the least important scaling parameters becomes necessary.

3.1 Froude Number Scaling

In practice, the model will be a reduced scale geometric facsimile of the bridge and suspension systems with a length scale given by Equation 3. Gravitational forces are invariably

$$l = n l_m \qquad 3$$

significant compared with inertial forces and therefore the model must be tested at a velocity given by Equation 4 determined by maintaining Froude number similarity (assuming that it

$$V_m = V n^{1/2} \qquad 4$$

is impractical to test in a different gravitational field). This implies a time scaling, parameter given by Equation 5.

$$\tau_m = \tau n^{1/2} \qquad 5$$

3.2 Reynolds Number Scaling

Since the model is normally tested in air at a much smaller scale compared with the full size bridge the Reynolds number similarity requirement will be in conflict with the Froude number requirement. However, the viscous forces are often small and relatively unimportant compared with the gravitational forces and it is not always necessary to accurately scale the Reynolds number. For example, if the bridge is made from components with sharp corners the Reynolds number dependency disappears and the assumption that the ratio of gravitational to viscous forces is dependent on Froude number alone will be correct. But with rounded corners, even with small radii, or with relatively long light streamlined shapes, the Reynolds number may become an important scaling parameter. Care must therefore be exercised in interpreting model data obtained from tests at a significantly lower Reynolds number than the full size bridge.

Further problems arise with small models where it is difficult to accurately reproduce an exact replica of the complex geometric shapes often associated with airportable bridges. Some simplification of geometrical characteristics is usually acceptable, but the extent is mostly left to the judgement of the experimenter.

3.3 Other Scaling Parameters

For complete dynamic similarity it is also necessary to scale the damping factor and elastic characteristics of both the bridge and suspension cables. The latter would require the model to be made from materials having a lower value of the modulus of elasticity in proportion to the geometric scale ratio. Since, in practice, the bridges are effectively suspended from a point, the elastic deformation of the bridge and the suspension cables is negligible compared with the displacement of the bridge in flight from its static equilibrium position. The bridge and cables can therefore be treated as rigid and it is not necessary to accurately scale their elastic and damping characteristics.

The mass distribution of the bridge and suspension cables should also be scaled according to the density parameters in Equation 2. However, this requirement may be relaxed since it is

not necessary to accurately scale the elastic and damping characteristics. It is sufficient to scale the weight and moments of inertia correctly according to Equations 6 and 7 respectively,

$$W_m = W/n^3 \qquad 6$$

$$I_m = I/n^5 \qquad 7$$

provided the position of the centre of gravity is also maintained. In most cases the angular accelerations are small and therefore the moments of inertia need only be scaled approximately.

3.4 Velocity Field

In the previous sections it has been assumed that the bridge is suspended in an airstream with a velocity distribution specified by the variable V. In the ideal situation the velocity field should include the effects of the rotor downwash as well as the turbulence or gustiness of the air through which the helicopter and bridge move.

Owing to the nonuniform velocity distribution over the rotor disc and the interference of the helicopter fuselage it is difficult to scale the downwash accurately. Fortunately, studies have shown that as the forward speed increases, the velocity field of the rotor is swept aft, and at speeds above 15 knot it will not influence the bridge to any great extent[2]. Below 15 knot, the rotor downwash exerts a force on the bridge which reduces the performance of the helicopter, especially in hover. Full scale tests have shown that at speeds up to 10 knot the rotor downwash induces an average pressure on the bridge of about 0·29 kPa (6 psf), although in some circumstances pressures up to 0·48 kPa (10 psf) have been found[2,4]. It is therefore only important to simulate rotor downwash for investigations near hover.

At heights above the earth's surface greater than about 300 m (1000 ft), depending on the roughness of the terrain, the natural wind turbulence is negligible, but it increases to a maximum of about 30 to 40% of the local mean windspeed near the ground. The effect of turbulence on the bridge depends on its scale relative to the bridge, its intensity, and its frequency spectrum. Although the airflow can be made turbulent in a wind tunnel, for example by using coarse turbulence grids upstream, it is not yet possible to simulate all of the natural wind properties particularly the physical size of gusts.

Both downwash and wind gusts can be partially simulated by careful experimentation using flow deflectors, different initial conditions, and by tapping or manually disturbing the model in various ways. Lack of similarity of downwash and gust effects should be borne in mind when interpreting model data.

4. CURRENT MODEL TESTS OF TWO CLASS 16 AIRPORTABLE BRIDGES

At the present time the Australian armed forces are using two different class 16 airportable bridges, namely a 16 m (52 ft) clear span bridge, and a 22 m (72 ft) raft, and there is a requirement for them to be transported on slings beneath Chinook helicopters.

The clear span bridge is similar to bridges which have been tested previously[1,2], but the raft is too heavy for a Chinook to carry in one section, and it is necessary to carry it in two separate loads which are different from any of the bridges tested previously.

In this section details of wind tunnel tests of a model of each of the two bridges are given. Specifically, the tests were aimed at determining the speed at which the bridges become unstable and the mode of instability, as well as the maximum speed at which they may be carried safely by a Chinook helicopter. Various slinging arrangements and stabilising devices are also investigated.

4.1 Full Scale Bridge Details

Two different bridges were considered: a 16 m (52 ft) clear span, and a 22 m (72 ft) raft. Both are fully decked class 16 type structures with ramps at each end and interlocking steel box centre sections which enable the span to be varied. The weights of the components and accessories that make up each complete bridge are given in Table 9[9]. The initial requirement was for each

TABLE 9
The Components and Their Weight Used to Make-up the 16 m (52 ft) Clear Span Bridge and the 22 m (72 ft) Raft[9].

Component	Weight per component kg (lb)	Number of components for each bridge	
		16 m (52 ft) Bridge	22 m (72 ft) Raft
Deck box	305·5 (672)	7	10
Ramp	346·4 (762)	4	4
Articulator	280·0 (616)		4
Sponson	128·6 (283)		4
Launching nose (3 stages)	149·6 (329)	1	
Rollers APB	13·6 (30)	6	2
Roller Packing APB	6·4 (14)	6	
Boat hooks	6·8 (15)	4	6
1 Ton Jacks APB	8·2 (18)	2	
Pin lifting APB	2·3 (5)	1	
Carrying bars	4·1 (9)	12	12
Ordnance pattern holdfast pickets	3·2 (7)	14	
Anchor kits	32·3 (71)		4
Accessory kits	17·3 (38)		4
Outboard motor	66·4 (146)		4
Fuel tanks (5 gal) full	23·2 (51)		8
Floats	29·6 (65)		20

bridge to be carried fully assembled in a horizontal attitude under a Chinook helicopter so that it could be easily positioned at the end of the flight. However, when a rotor downwash load factor of 0·48 kPa (10 psf) was applied the raft became too heavy for a Chinook helicopter to carry in one lift. Even with a less conservative load factor of 0·29 kPa (6 psf), the load would have remained in excess of the 9100 kg (20,000 lb) limit set down to ensure that the helicopter did not become overloaded during lift-off and hover. Consequently, the raft had to be carried in two separate loads, designated load A and B in this report. This precludes the raft from being positioned by helicopter as a complete unit. Details of each bridge are given in Table 10 and Figures 2 and 3[9].

Actual values of the moments of inertia of each load are unknown and the values quoted in Table 10 are estimated values. For the 16 m (52 ft) clear span bridge, and load B of the raft, the moments of inertia were calculated assuming each structure had a uniform density determined from its known weight and external dimensions. For load A of the raft it was also assumed that the deck boxes, sponsons, and auxiliary equipment on top of the boxes and sponsons, all had a uniform density, but the outboard motors and fuel tanks placed in each sponson were treated as concentrated masses.

The three loads were to be rigged with four leg Aeroquip sling assembles[9]. Each leg of the sling was to be twisted one complete turn for each metre (3 ft) of sling length to break up the trailing vortex system and minimise sling leg flapping during flight. Despite this, some leg flapping is still likely to occur, and care should be taken to protect the sling legs from wear on the lower and upper edges of the bridges. Details of the slinging arrangements proposed are shown in Figures 2 and 3[9].

Previous tests have shown that bridges should preferably be carried with their span parallel to the direction of motion[1,2,3]. This significantly reduces the aerodynamic load on the bridge, especially at high speeds, and leads to much smaller loads on the hook as well as an improvement in stability. Details of fins which have been proposed for stabilising the 16 m (52 ft) bridge

TABLE 10

Principal Details of the 16 m (52 ft) Clear Span Bridge, and the 22 m (72 ft) Raft[9].

Bridge	16 m (52 ft) clear span bridge	22 m (72 ft) raft Complete	22 m (72 ft) raft Load A	22 m (72 ft) raft Load B
Weight (fully rigged)	3600 kg (7910 lb)	7350 kg (16170 lb)	4760 kg (10480 lb)	2580 kg (5690 lb)
Length	15·9 m (52 ft)	22·0 m (72 ft)	12·2 m (40 ft)	9·8 m (32 ft)
Width	3·7 m (12 ft)	6·1 m (20 ft)	6·1 m (20 ft)	3·7 m (12 ft)
Height	0·41 m (1·33 ft)	—	1·2 m (4 ft)	0·41 m (1·33 ft)
Downwash load factor	0·48 kPa (10 psf)	0·48 kPa (10 psf)	0·48 kPa (10 psf)	0·48 kPa (10 psf)
Downwash load	2840 kg (6240 lb)	3930 kg (8640 lb)	2620 kg (5760 lb)	1750 kg (3840 lb)
Total effective load at hover	6440 kg (14150 lb)	11280 kg (24810 lb)	7380 kg (16 240 lb)	4330 kg (9530 lb)
Static incidence	Unknown possibly 2° nose up	—	Unknown possibly 2° nose up	Unknown possibly horizontal
Stabilization	Fins (see figure 4)	—	Not recommended	Fins (see figure 4)
Ixx (Estimated values)	4050 kgm^2 (96,000 lbft^2)	—	11,600 kgm^2 (274,000 lb ft^2)	2950 kgm^2 (69,800 lbft^2)
Iyy (Estimated values)	55,800 kgm^2 (1,320,000 lbft^2)	— —	89,100 kgm^2 (2,110,000 lbft^2)	14,600 kgm^2 (346,000 lbft^2)
Izz (Estimated values)	52,000 kgm^2 (1,230,000 lbft^2)	—	78,600 kgm^2 (1,860,000 lbft^2)	11,700 kgm^2 (278,000 lbft^2)
Recommended sling leg length	13·1 m (43 ft)	—	13·1 m (43 ft)	13·1 m (43 ft)

Load A: Consists of ten deck boxes, four sponsons, twenty floats, four anchor kits, and four accessory kits, plus one outboard motor and two fuel tanks stored in each sponson.

Load B: Consists of four ramps and four articulators.

and load B of the raft are given in Figure 4[9]. These fins are quite different from the 'flat' fins successfully used by Bradley and Toms, shown in Figure 1[2]. It was suspected that the '*V*' fins proposed might produce excessive drag and lead to a large trail angle and a longitudinal instability at low speed. Fins had not been proposed for load A of the raft because the auxiliary equipment was placed aft and was expected to provide the necessary load stability.

4.2 Model Bridges

Three models were made and tested in the wind tunnel. One was a model of the complete 16 m (52 ft) clear span bridge, and the other two were models of load A and load B which made up the 22 m (72 ft) raft. Model size was limited both by the need to investigate the effects of varying the length of the suspension cable, and to avoid uncertain and varying blockage corrections produced when the bridge oscillates under test. A conservative model scale of 1/15 was selected. For the 16 m (52 ft) clear span bridge the corresponding model was 1·06 m (3·5 ft) long and 0·24 m (0·80 ft) wide.

The models were made from balsa wood. It was not practical to reproduce all the structural

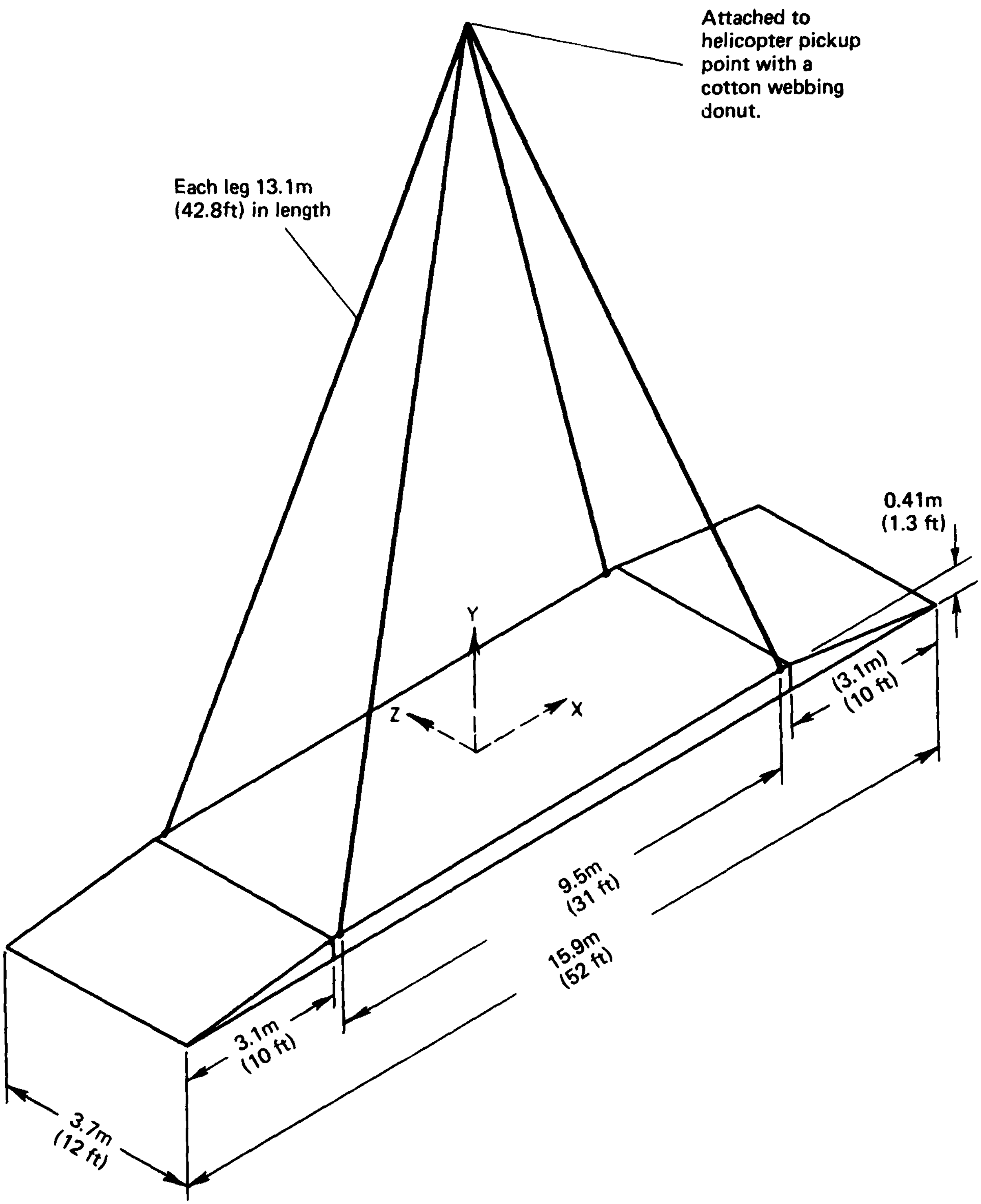


FIG 2 MAJOR DIMENSIONS OF THE 16M (52FT) CLEAR SPAN BRIDGE

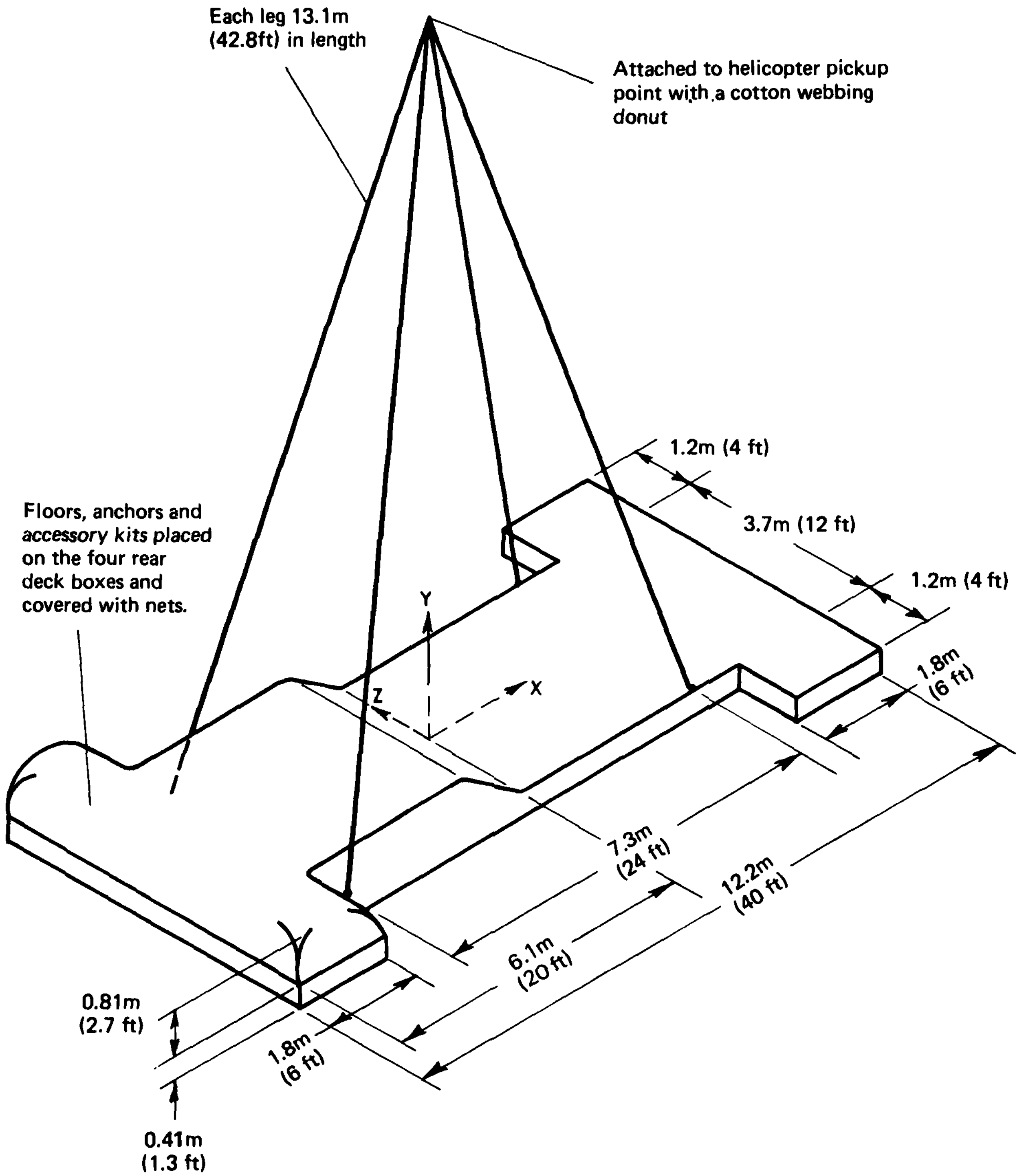


FIG.3 MAJOR DIMENSIONS OF THE 22M (72FT) RAFT CARRIED IN TWO LOADS.
(a) Load A

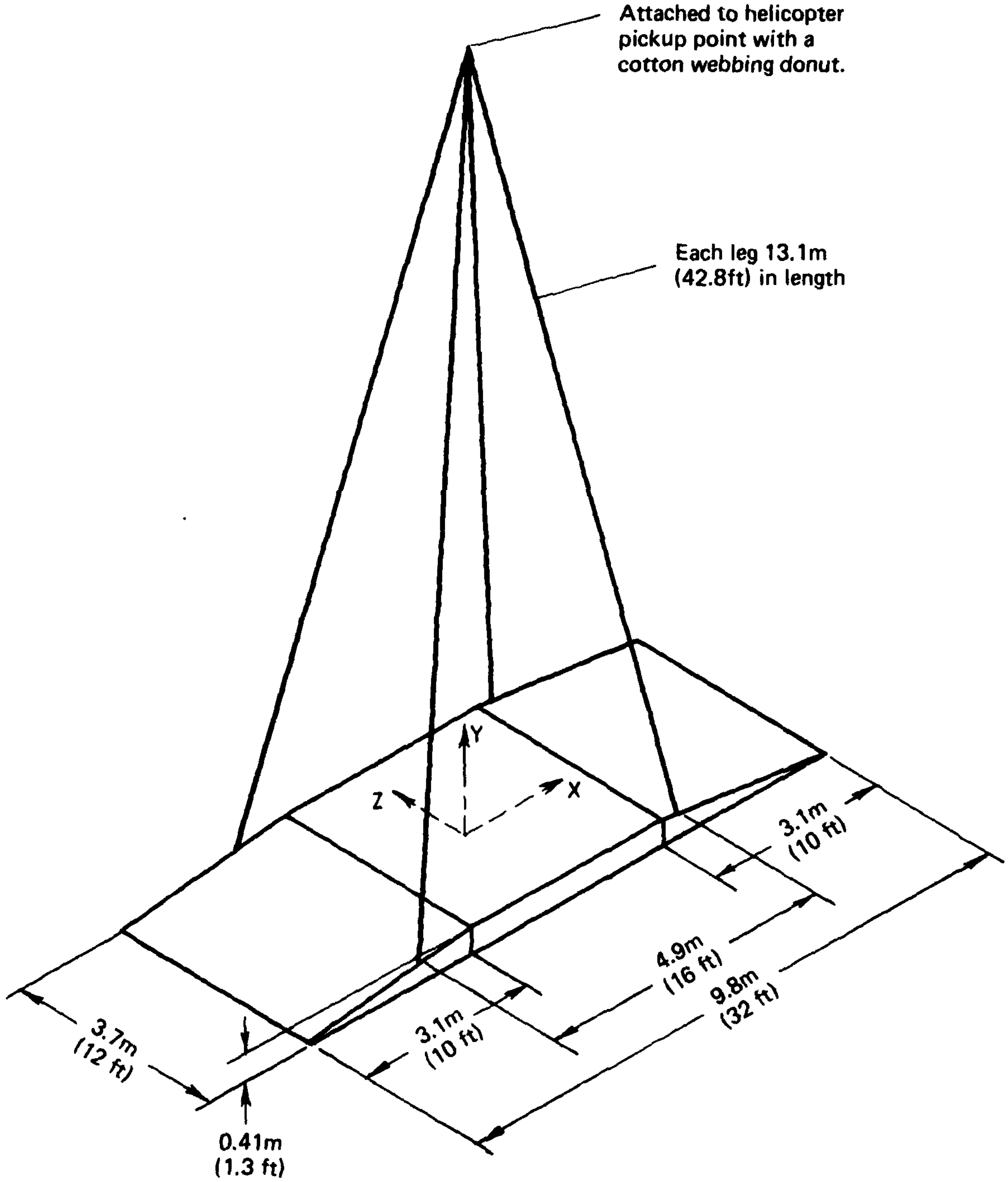


FIG.3 (Cont.)
(b) Load B

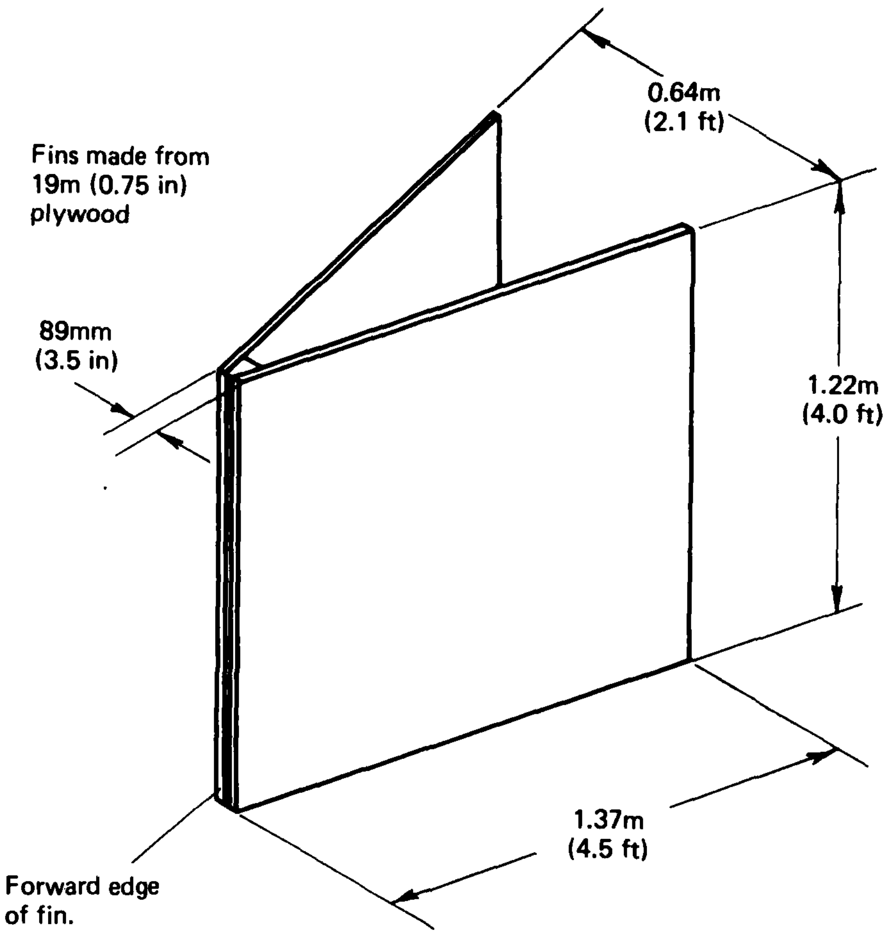
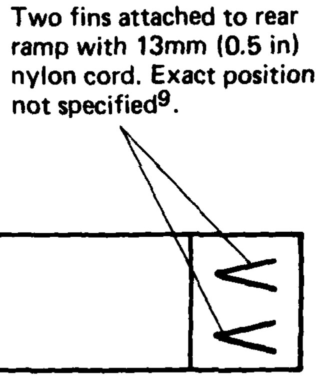
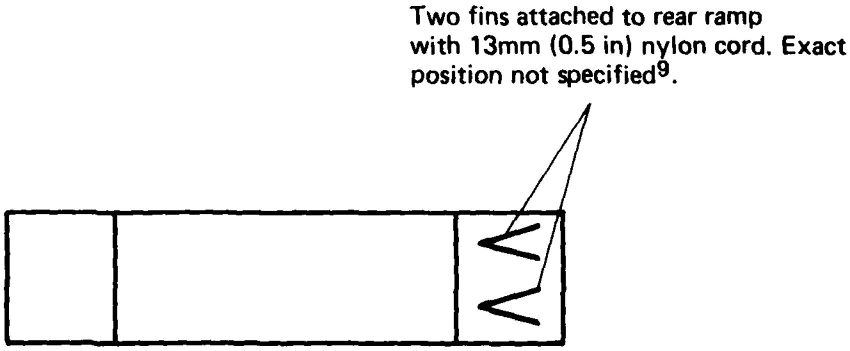


FIG 4 INITIALLY PROPOSED V TYPE STABILIZING FINS FOR THE 16M (52 FT) CLASS 16 BRIDGE AND LOAD B OF THE 22M (72FT) RAFT.
(a) Size of fins.



16m (52 ft) Clear span bridge.



22m (72 ft)Raft – Load B

FIG.4 (Cont.)
(b) Position of the fins.

details and only those features considered necessary for the correct dynamic behaviour were incorporated. Photos of the models are shown in Figure 5.

The equations in section 3 give the relevant scaling factors between the models and full size bridges. The weight of each bridge was correctly scaled. Inlaid metal weights were used to obtain the correct relationship between weight, the position of the centre of gravity, and the moments of inertia. However, the moments of inertia were only reproduced to within 5% of the estimated values in Table 10. Approximating the moments of inertia in this manner is not expected to cause any significant error in the motion of the bridges because the angular accelerations are usually quite small. The main details of each model are given in Table 11.

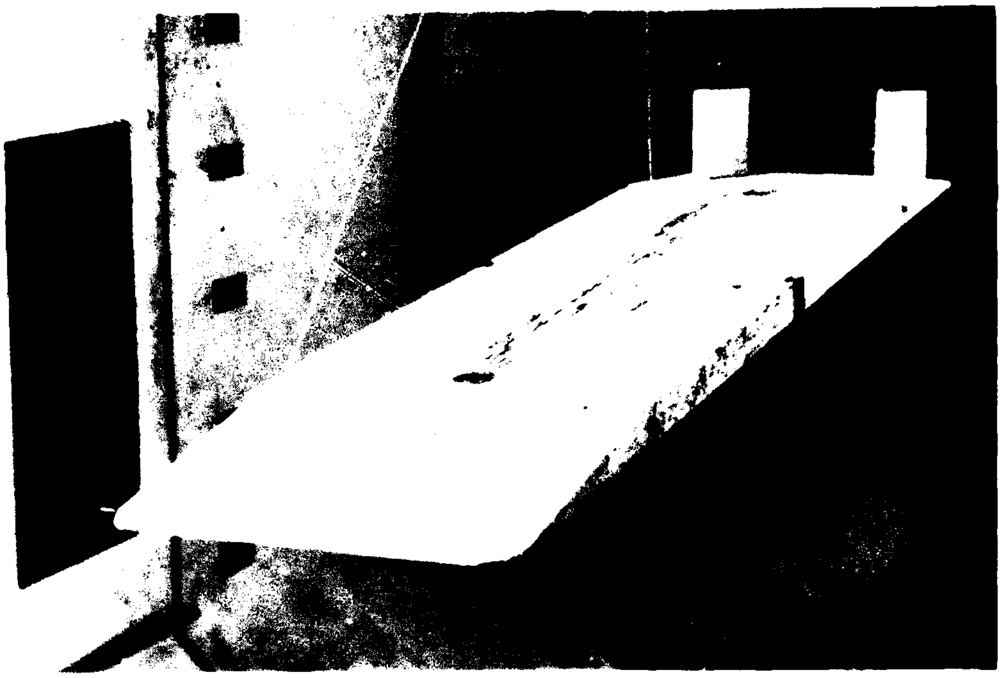
TABLE 11
Principal Details of Each Model.

Bridge	16 m (52 ft) clear span	22 m (72 ft) raft	
		Load A	Load B
Scale	1/15	1/15	1/15
Weight	1·07 kg (2·35 lb)	1·41 kg (3·11 lb)	0·76 kg (1·67 lb)
Length	1·06 m (3·47 ft)	0·813 m (2·66 ft)	0·650 m (2·14 ft)
Width	0·244 m (0·80 ft)	0·406 m (1·33 ft)	0·244 m (0·80 ft)
Height	0·027 m (0·089 ft)	0·081 m (0·266 ft)	0·027 m (0·089 ft)
Recommended length of sling legs	0·87 m (2·86 ft)	0·87 m (2·86 ft)	0·87 m (2·86 ft)
Stabilization	Fins	None	Fins
Ixx	0·0052 kgm^2 (0·122 lbft^2)	0·015 kgm^2 (0·345 lbft^2)	0·0037 kgm^2 (0·088 lbft^2)
Iyy	0·074 kgm^2 (1·76 lbft^2)	0·119 kgm^2 (2·81 lbft^2)	0·019 kgm^2 (0·459 lbft^2)
Izz	0·073 kgm^2 (1·72 lbft^2)	0·108 kgm^2 (2·56 lbft^2)	0·016 kgm^2 (0·378 lbft^2)

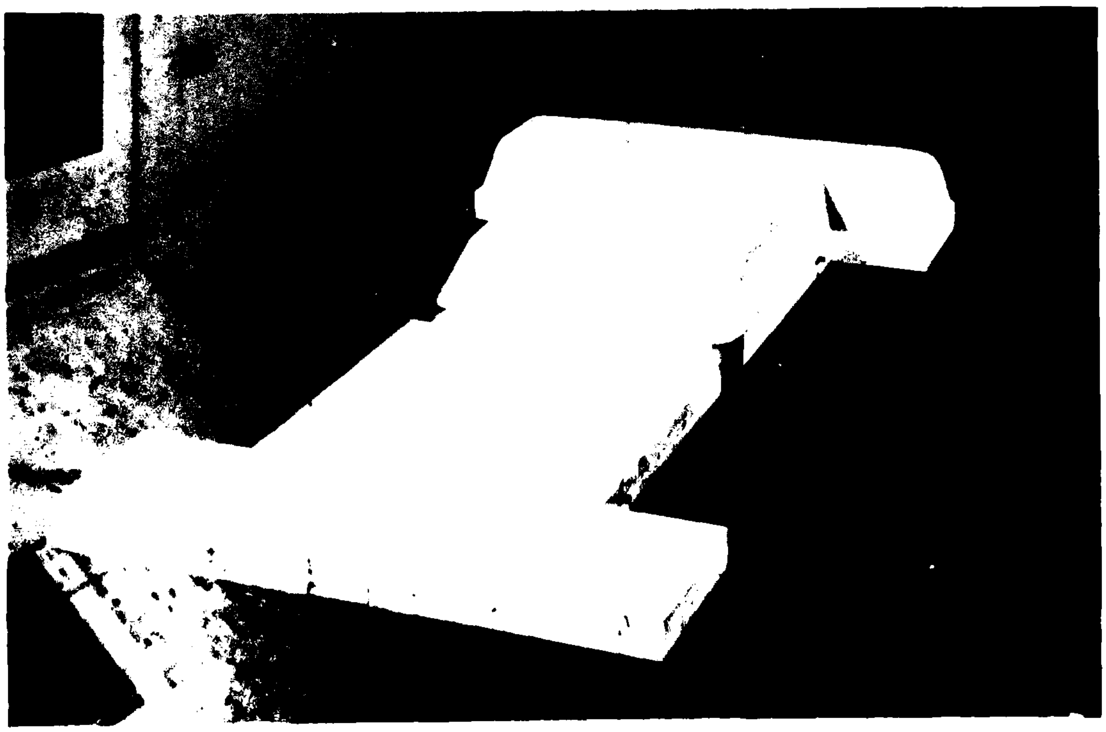
The models were each suspended from a hook fixed 150 mm (6 in) below the ceiling of the wind tunnel working section using the slinging method proposed for the full scale bridges as shown in Figures 2 and 3. Only single point suspension systems were used because multi hook suspension systems are not currently available on existing Australian helicopters. The four sling legs were modelled with 1·5 mm (0·06 in) diameter cord. The sling legs are therefore only approximately scaled because the actual full size sling straps had a thin cross section which was 6 cm (2·5 in) wide, and each leg was twisted one complete revolution for each metre of length. The four cords were knotted together and attached to the hook with a very short length of cable to approximate the donut used on the full scale bridges. The length of each leg could be adjusted as required.

Models of the V type stabilising fins shown in Figure 4 were also made from balsa wood. These fins could be attached to each bridge model as required. Models of two sets of plain flat stabilising fins were also made. The first set had a full scale length of 1·37 m (4·5 ft) and a height of 1·22 m (4·0 ft) which is the same length and height as the V fins, and provision was made for attaching the fins to the aft of the bridge, one at each side. The second set of flat fins had the same length as the first, but were only half the height.

As discussed earlier in Section 2.3, the rotor downwash was not modelled. Although the dynamics of the helicopter in the fore and aft, and lateral directions were approximated by tapping and displacing the model, the motion in the vertical direction was not simulated.



(a) 16m (52 ft) clear span bridge fitted with V type fins.



(b) 22m (72 ft) raft, load A.

FIG 5 BRIDGE MODELS

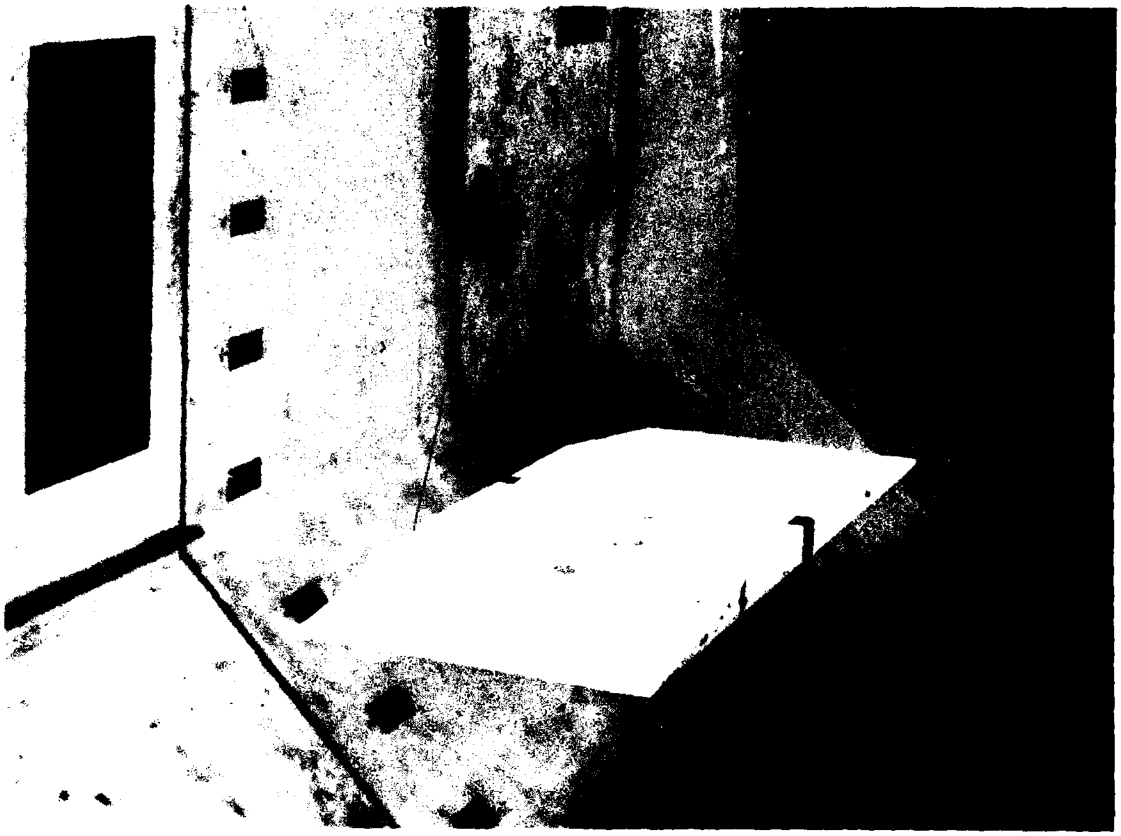


FIG 5 (Cont.)
(c) 22m (72 ft) raft, load B.

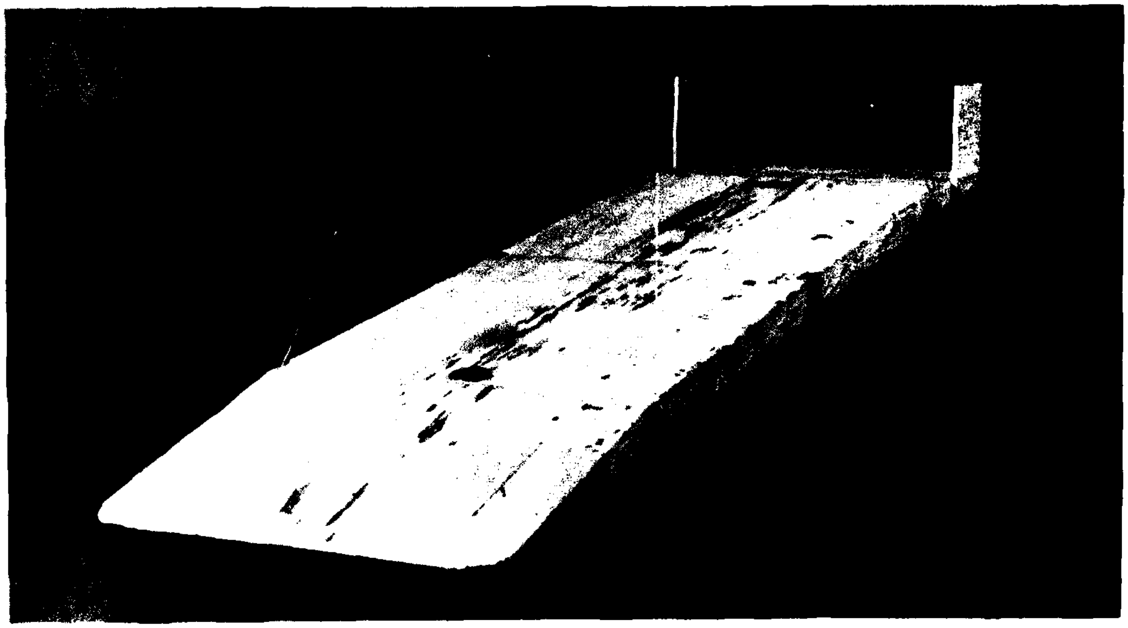
4.3 Model Tests

Each model bridge was attached in turn to a hook in the ceiling of the 2·7 m (9 ft) × 2·1 m (7 ft) low speed wind tunnel, and the airspeed increased in steps equivalent to 5 knot full scale until either a divergent oscillation was encountered, or there was a sustained oscillation judged to be of sufficient amplitude to make the full scale helicopter uncontrollable. The oscillation of the bridge was either self excited or initiated by physically displacing or tapping it with a long probe. The maximum manual disturbance to the model consisted of ± 30° yaw, ± 20° longitudinal displacement, ± 20° lateral displacement, and various combinations, from the steady state or equilibrium position at the time. Disturbing the model in this way enabled the effects of wind gusts and helicopter manoeuvres in the horizontal plane to be approximated. The model could not be directly disturbed in the vertical plane and the effects of motion in this plane were not simulated. Each test was repeated to check both the mode and speed at which the instability occurred.

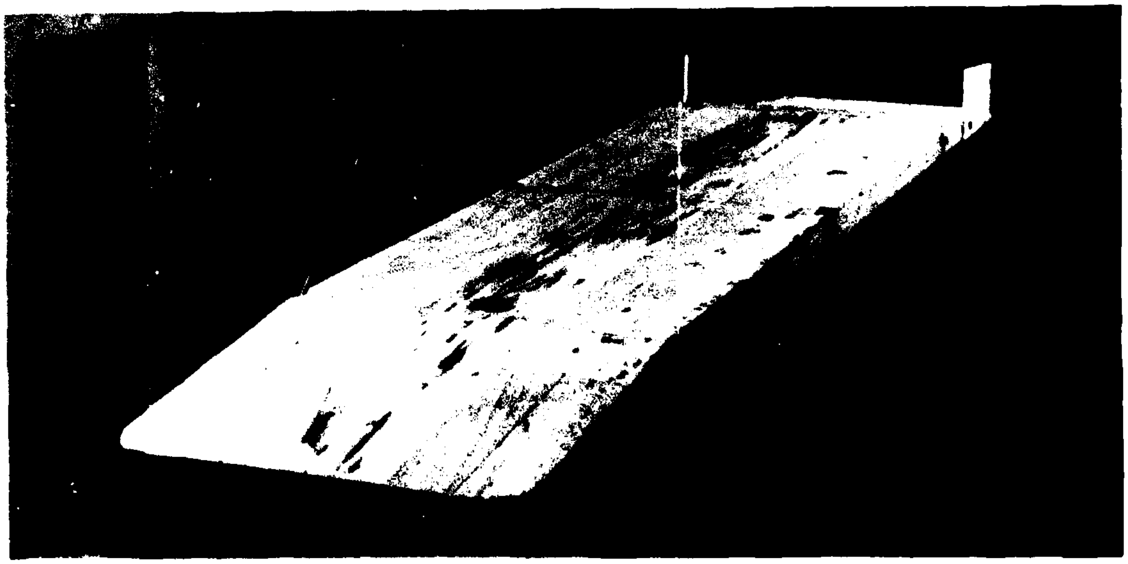
The models were tested with three different lengths of suspension cable: the recommended length equivalent to 13 m (43 ft) full scale, a longer length of 16 m (53 ft), and a shorter length of 10 m (33 ft). In each case the tests were made with the models initially rigged in the 'wind off' condition at attitudes of 5° nose up, horizontal, and 5° nose down.

The models were initially tested without any stabilizing fins, then with the V type fins shown in Figure 4, which had been proposed previously[9], and finally with the two sets of flat fins described in Section 4.2 and shown attached to the 16 m (52 ft) clear span model in Figure 6.

The results of the tests are presented and discussed in the next section.



(a) Large flat fins.



(b) Small flat fins

FIG 6 16M (52 FT) CLEAR SPAN BRIDGE MODEL FITTED WITH FLAT FINS.

5. TEST RESULTS AND COMMENTS

The results for each model, given below, have all been extrapolated to apply to the full size bridges by using the appropriate equations in Section 3.

5.1 16 m (52 ft) Clear Span Bridge

The results for the 16 m (52 ft) clear span bridge are given in detail in Table 12. The maximum stable speed and mode of instability for each configuration are summarized in Table 13.

5.1.1 Bridge without Fins

With an initial static 5° nose up, or horizontal attitude, the bridge turned broadside at low speed, but experienced a rather large and sometimes irregular yaw oscillation of up to ±40°. As the speed increased this yaw oscillation became smaller, and the bridge became 'stable' in the broadside position. A small erratic oscillation occurred at about 50 knot. At 65–70 knot the bridge experienced a longitudinal oscillation of about ±4°, which was usually combined with a yaw motion of ±5° and a lateral oscillation of ±3°. These motions of the bridge would produce large fluctuating forces on the helicopter and it was considered that they would prevent higher speeds from being achieved safely. At airspeeds above 70 knot, the oscillations became much larger in amplitude, but they were not naturally divergent up to the maximum test speed of 110 knot.

No improvement in stability was achieved by rigging the bridge 5° nose up compared with a horizontal attitude. This was to be expected, because the effects of a nose up attitude would be negated by the bridge being broadside. However, at 5° nose up, a relatively large manual disturbance from the broadside position at 75 knot induced a yaw oscillation which increased in amplitude until the bridge suddenly yawed through a further 90° to turn end for end and the resulting high nose down incidence caused large forces to be suddenly exerted on the cables causing them to fail.

When the bridge was tested with an initial nose down attitude of 5°, the drag force was sufficient to overcome the yawing moment tending to turn it to its otherwise stable broadside position, and the span remained aligned with the vertical flight plane up to a speed of 55–60 knot where a naturally induced divergent yaw-lateral oscillation occurred.

Changing the length of the suspension cable from 10 m (33 ft) to 16 m (53 ft) had virtually no effect on the speed or mode of instability for a given initial bridge attitude between 5° nose up and 5° nose down.

The results are in reasonable agreement with previous results predicted for a 15 m (50 ft) class 16 bridge given in Table 2. In both cases similar modes of instability occurred but slightly lower limiting speeds were found from the current tests.

The present tests indicate that if the bridge is carried without stabilising devices, such as fins, it should be rigged either horizontally or 1 to 2 degree nose up on cables from 10 m (33 ft) to 16 m (53 ft) in length where it will fly broadside and its speed will be limited to 65 knot by a longitudinal or combined yaw-longitudinal oscillation.

5.1.2 Bridge Fitted with V Fins

The V fins forced the bridge to fly with its longitudinal axis aligned with the airflow above a speed of about 10 knot. A small low frequency yaw oscillation usually occurred, but it died out as the speed increased. These fins have the required effect of aligning the bridge with the airstream, and this should reduce the aerodynamic forces on the suspension hook compared with the bridge without fins.

In all cases, the bridge had a higher stable speed when fitted with V fins than without fins. The maximum increase in speed of 20 knot occurred when the bridge was suspended either horizontally or 5° nose up on the 10 m (33 ft) cable. Increasing the length of the suspension cable was destabilising when the bridge was rigged horizontally or 5° nose up, but had no effect when it was 5° nose down. (This is contrary to the results without fins when altering the length of the suspension cable did not effect stability). In addition, a 5° nose up or 5° nose down attitude

TABLE 12

Speed and Mode of Instability for the 16 m (52 ft) Clear Span Bridge Determined from Tests of a 1/15 Scale Model.

(a) Bridge without Fins.

α (degree)	Suspension cable length m (ft)	Comments and mode of instability	Maximum stable speed (knot)
0	10 (33)	Bridge yawed to a broadside position at 10 knot with a low frequency yaw oscillation of ±30° which decreased in amplitude as the speed increased. At 60 knot a ±4° longitudinal oscillation was manually induced, and this combined with an erratic ±5° yaw and ±3° lateral motion at 70 knot.	65
0	13 (43)	Bridge yawed to a broadside position at 10 knot, with an irregular low frequency yaw oscillation of ±40° which decreased as the speed was increased. At 70 knot a ±3° longitudinal oscillation was induced which combined with a ±3° lateral motion and a ±3° yaw motion. At 80 knot, ±6° longitudinal oscillation occurred with an erratic ±10° yaw and ±5° lateral motion.	70
0	16 (53)	Bridge yawed to a broadside position at 5 to 10 knot, with an irregular low frequency yaw oscillation of ±40° which decreased as the speed increased. At 70 knot bridge returned to a mean yaw angle of 45° with ±30° yaw oscillation coupled with a large lateral and longitudinal oscillation.	65
+5° (nose up) +5° (nose up) +5° (nose up)	10 (33) 13 (43) 16 (53)	Bridge yawed to a broadside position at 10 knot with an irregular low frequency yaw oscillation of ±40° which decreased in amplitude as the speed increased. Small erratic motion at 50 knot. At 70 knot, ±5° yaw, and ±3° lateral-longitudinal oscillation which damped very slowly. At 75 knot a relatively large manual yaw disturbance increased in amplitude until the bridge flipped through a further 90° yaw to fly end for end at about 20° nose down where one of the sling legs failed.	65
−5° (nose down)	10 (33)	Bridge remained aligned with the flow. At 40 knot bridge flew 8° nose down, and at 50 knot bridge had a 10° nose down attitude with a ±3° yaw oscillation and a ±1° longitudinal oscillation. Naturally induced divergent lateral (yaw) oscillation at 60 knot.	55
−5° (nose down)	13 (43)	Bridge remained aligned with flow. At 50 knot bridge flew 9° nose down with ±5° yaw and ±1° longitudinal oscillation. Naturally induced divergent combined yaw-lateral oscillation at 60 knot.	55
−5° (nose down)	16 (53)	Bridge remained aligned with flow. At 50 knot there was a sustained ±10° yaw oscillation and bridge had an 8° nose down attitude. Naturally induced divergent lateral (yaw) oscillation at 55 knot.	50

TABLE 12.—Continued
(b) Bridge Fitted with V Fins.

α (degree)	Suspension cable length m (ft)	Comments and mode of instability	Maximum stable speed (knot)
0	10 (33)	Bridge remained aligned with airflow and flew 4° nose down at 60 knot, and 12° nose down at 80 knot with slight longitudinal oscillation. At 90 knot, bridge rotated longitudinally to high incidence with large erratic yaw-lateral-longitudinal motion.	85
0	13 (43)	Bridge remained aligned with airflow and flew 10° nose down at 80 knot with small longitudinal oscillation. Naturally induced divergent yaw-lateral oscillation occurred at 90 knot with a trail angle of approximately 17°. (Yaw oscillation occurred about the fins).	85
0	16 (53)	Bridge remained aligned with airflow and flew 3° nose down at 70 knot with small yaw-lateral oscillation. Naturally induced slowly divergent yaw-lateral oscillation at 80 knot. (Yaw oscillation occurred about the fins).	75
+5° (nose up)	10 (33)	Bridge remained aligned with airflow and flew 2° nose up at 70 knot with slight yaw-lateral movement. A strong manual input disturbance caused a divergent yaw-lateral oscillation to occur at 90 knot. (Yaw motion occurred about the fins).	85
+5° (nose up)	13 (43)	Bridge remained aligned with airflow and flew 3° nose up at 60 knot. At 70 knot a slight yaw-lateral oscillation occurred which became naturally divergent at 80 knot. (Yaw oscillation occurred about the fins).	75
+5° (nose up)	16 (53)	Bridge remained aligned with airflow and flew 3° nose up at 60 knot, with a small longitudinal oscillation. Manually induced longitudinal oscillations damped very slowly. A small manual disturbance at 70 knot induced a divergent yaw-lateral oscillation. (Yaw-oscillation occurred about the fins).	65
−5° (nose down)	10 (33)	Bridge remained aligned with airflow and flew 10° nose down at 50 knot, and 16° nose down at 60 knot. At 65 knot the nose down attitude increased to 20° and a ±4° longitudinal oscillation occurred with erratic yaw-lateral motion.	60
−5° (nose down)	13 (43)	Bridge remained aligned with the airflow and flew 10° nose down at 50 knot, and 14° nose down at 60 knot with a sustained small yaw-lateral oscillation. Naturally induced divergent yaw-lateral oscillation occurred at 65 knot. (Yaw oscillation occurred about the fins).	60
−5° (nose down)	16 (53)	Bridge remained aligned with the airflow and flew 9° nose down at 50 knot, and 12° nose down at 60 knot with a sustained small yaw-lateral oscillation. Naturally induced divergent yaw-lateral oscillation occurred at 65 knot. (Yaw oscillations occurred about the fins).	60

Note: At 60 knot a large longitudinal manual disturbance caused the bridge to rotate longitudinally to a very high incidence and the bridge would almost certainly have contacted the tail of the helicopter.

TABLE 12—Continued

(c) Bridge fitted with large flat fins, height 1·22 m (4·0 ft), length 1·37 m (4·5 ft).

α (degree)	Suspension cable length m (ft)	Comments and mode of instability	Maximum stable speed (knot)
0	10 (33)	Bridge flew aligned with airflow, 4° nose down at 60 knot, and 9° nose down at 80 knot. Manual disturbance damped quickly but there was a slight erratic motion. At 90 knot bridge rotated longitudinally to a large nose down attitude with severe longitudinal oscillation and slight yaw-lateral motion.	85
0	13 (43)	Bridge flew aligned with airflow, 4° nose down at 60 knot, and 14° nose down at 90 knot with slight yaw-lateral-longitudinal motion. Naturally induced divergent yaw-lateral oscillation occurred at 95 knot with approximately 17° nose down attitude. Yaw oscillation occurred about an axis approximately half the bridge span aft of the fins.	90
0	16 (53)	Bridge flew aligned with airflow, 3° nose down at 70 knot, and 7° nose down at 90 knot with slight yaw-lateral motion. Manual disturbance induced a yaw-lateral oscillation at 100 knot. Naturally unstable at 105 knot. Yaw oscillation occurred about an axis approximately half the bridge span aft of the fins.	95
+5° (nose up)	10 (33)	Bridge flew aligned with airflow, 2° nose up at 70 knot, 4° nose down at 90 knot. Manual disturbance damped slowly. Bridge rotated longitudinally to a large nose down attitude at 100 knot with erratic motion.	95
+5° (nose up)	13 (43)	Bridge flew aligned with airflow, 2° nose up at 70 knot. Sustained naturally induced small yaw-lateral oscillation at 80 knot. Naturally induced divergent yaw-lateral oscillation at 85 knot. Yaw oscillation occurred about an axis approximately half the bridge span aft of the fins.	80
+5° (nose up)	16 (53)	Bridge flew aligned with airflow, slight erratic motion at 60 knot. Naturally induced divergent yaw-lateral oscillation at 70 knot. Yaw oscillation occurred about an axis approximately half the bridge span aft of the fins.	65
−5° (nose down)	10 (33)	Bridge flew aligned with airflow, 9° nose down at 50 knot, and 15° nose down at 60 knot. Bridge rotated longitudinally to a large angle of incidence at 70 knot with ±4° long period longitudinal oscillations and erratic yaw-lateral oscillations.	65
−5° (nose down)	13 (43)	Bridge flew aligned with airflow, 9° nose down at 50 knot, and 13° nose down at 60 knot. Naturally induced divergent lateral-(yaw) oscillation at 70 knot.	65
−5° (nose down)	16 (53)	Bridge flew aligned with airflow, 8° nose down at 50 knot, and 13° nose down at 65 knot with ±2° yaw-lateral longitudinal motion. Naturally induced divergent yaw-lateral oscillation at 70 knot. Yaw oscillation occurred about an axis approximately half the bridge span aft of the fins.	65

TABLE 12.—Continued

(d) Bridge fitted with small flat fins, height 0·61 m (2·0 ft), length 1·37 m (4·5 ft)

α (degree)	Suspension cable length m (ft)	Comments and mode of instability	Maximum stable speed (knot)
0	10 (33)	Bridge flew aligned with airflow, 4° nose down at 60 knot, and 9° nose down at 80 knot with a small irregular yaw-lateral-longitudinal oscillation. At 85 knot the nose down attitude became large with severe longitudinal disturbances.	80
0	13 (43)	Bridge flew aligned with airflow, 4° nose down at 60 knot, and 9° nose down at 80 knot with a small lateral oscillation. Sustained ±10° lateral oscillation at 85 knot, which became naturally divergent at 90 knot. Very little yaw oscillation (±1° to ±2°) occurred.	80
0	16 (53)	Bridge flew aligned with airflow, 2° nose down at 60 knot, and 6° nose down at 90 knot with ±3° yaw and ±3° lateral oscillation. Naturally induced divergent lateral-(yaw) oscillation at 95 knot.	85
+5° (nose up)	10 (33)	Bridge flew aligned with airflow, 1° nose up at 70 knot, and 4° nose down at 90 knot. Bridge rotated longitudinally to approximately 40° incidence with an erratic longitudinal oscillation at 100 knot.	95
+5° (nose up)	13 (43)	Bridge flew aligned with airflow, 1° nose up at 70 knot, 5° nose down at 100 knot, and 9° nose down at 110 knot where ±5° yaw and ±2° lateral oscillation occurred. At 115 knot bridge rotated longitudinally to approximately 40° nose down with a large amplitude irregular longitudinal motion.	105
+5° (nose up)	16 (53)	Bridge flew aligned with airflow, 2° nose up at 70 knot, and 6° nose down at 110 knot. At 120 knot the nose down incidence increased abruptly to approximately 30°, and there was a large amplitude irregular longitudinal oscillation.	110
−5° (nose down)	10 (33)	Bridge flew aligned with airflow with 9° nose down and ±1° longitudinal oscillation at 50 knot. A small manual input disturbance caused a divergent lateral oscillation at 60 knot.	55
−5° (nose down)	13 (43)	Bridge flew aligned with airflow, 9° nose down at 50 knot. Sustained ±20° lateral oscillation at 60 knot, with ±2° yaw, became a naturally divergent lateral-(yaw) oscillation at 65 knot.	55
−5° (nose down)	16 (53)	Bridge flew aligned with airflow, 9° nose down at 50 knot. Naturally induced divergent lateral oscillation at 60 knot.	55

was destabilising compared with the horizontal attitude. An initial nose down attitude should be avoided as this causes the bridge to settle at a high angle of incidence where large aerodynamic forces will be produced and transmitted to the helicopter. Nose up attitudes greater than 5° to 10° should also be avoided because any longitudinal oscillation which may be induced in-

TABLE 13
Summary of Speed and Mode of Instability Predicted for the 16 m (52 ft) Clear Span Bridge.

α (degree)	Suspension cable length m (ft)	Speed (knot) and mode of instability			
		No fins	Vee fins	Large flat fins	Small flat fins
0	10 (33)	65 longitudinal-erratic	85 longitudinal	85 longitudinal	80 longitudinal
	13 (43)	70 longitudinal-erratic	85 yaw-lateral	90 yaw-lateral	80 lateral
	16 (53)	65 yaw-lateral-longitudinal	75 yaw-lateral	95 yaw-lateral	85 lateral-(yaw)
+5 (nose up)	10 (33)	65 yaw-longitudinal	85 yaw-lateral	95 longitudinal (erratic)	95 longitudinal
	13 (43)	65 yaw-longitudinal	75 yaw-lateral	80 yaw-lateral	105 longitudinal
	16 (53)	65 yaw-longitudinal	65 yaw-lateral	65 yaw-lateral	110 longitudinal
−5 (nose down)	10 (33)	55 lateral-(yaw)	60 longitudinal	65 longitudinal	55 lateral
	13 (43)	55 yaw-lateral	60 yaw-lateral	65 lateral-(yaw)	55 lateral-(yaw)
	16 (53)	50 lateral-(yaw)	60 yaw-lateral	65 yaw-lateral	55 lateral

advertently will damp slowly, and the resulting high positive angle of attack which occurs on the forward swing may cause the bridge to 'float' up and contact the fuselage of the helicopter.

When the bridge was suspended on the 10 m (33 ft) cable it usually moved aft and rotated longitudinally to a high nose down attitude where large amplitude longitudinal oscillations limited its speed. With longer cables, the speed was limited to a slightly lower value by a naturally divergent yaw lateral oscillation, the yaw motion occurring about an aft point midway between the fins.

Overall the most suitable attitude was 1 to 2 degree nose up, where the limiting speed was 85 knot for a suspension cable between 10 m (33 ft) and 13 m (43 ft) in length. The results indicate that the V fins do have a significant stabilising effect and they allow higher speeds to be achieved, especially with short cables.

5.1.3 Bridge Fitted with Large Flat Fins

Like the V fins, the large flat fins forced the bridge to fly with its span aligned with the vertical flight plane above about 10 knot. However, the bridge usually had a slightly smaller incidence at a given speed. This lower incidence results from the smaller drag of the flat fins compared with the V fins, which, in turn leads to smaller aerodynamic forces on the bridge and the suspension hook.

The stable speed of the bridge fitted with large flat fins was approximately 5 knot higher than the bridge with V fins. When the bridge was rigged 5° nose down, changing the length of the suspension cable did not alter the stable speed, but when it was rigged 5° nose up, higher stable

speeds were achieved with shorter cables. Similar cable length effects had been found previously with the V fins. However, the results with the flat fins were contrary to the results with the V fins when the bridge was initially rigged horizontally. In this position, increasing the length of the suspension cable allowed higher speeds to be achieved with the flat fins.

The bridge experienced similar modes of instability with the flat fins as it did with the V fins. On the 10 m (33 ft) cable the bridge had a longitudinal mode of instability, but on the 13 m (43 ft) and 16 m (53 ft) cables it had a yaw-lateral mode of instability. When the yaw-lateral oscillation occurred the yaw motion always had the same frequency as the lateral oscillation, and it occurred about a point approximately half the span of the bridge aft of the fins.

The large flat fins produced maximum stability when the bridge was slung either 5° nose up on the 10 m (33 ft) cable, or horizontally on a 16 m (53 ft) cable, the limiting speed being 95 knot in each case. This was 10 knot higher than achieved with the V fins. Overall the large flat fins performed better than the V fins, but the difference was not as great as had been expected.

5.1.4. Bridge Fitted with Small Flat Fins

The small flat fins did not make the bridge as directionally stable at low speeds as the large flat fins or the V fins. Rather large yaw oscillations occurred below 10 knot and the bridge did not align with the airflow until a speed of about 15 knot was reached.

There was little difference in the trail angle with either the large or small flat fins, and any reduction in drag resulting from the small fins was not evident in a reduced trail angle or bridge incidence.

With the bridge rigged horizontally, the maximum speed was 10 knot lower than with the large flat fins, but was still greater than without fins. The mode of instability was virtually the same for both the small and large flat fins.

With the bridge initially suspended 5° nose up on the 10 m (33 ft) cable the speed was the same for both sets of flat fins. As the suspension cable was increased in length from 10 m (33 ft) to 16 m (53 ft) the limiting speed for the bridge with small flat fins increased from 95 knot to 110 knot. However, the opposite occurred when either the large flat fins or the V fins were fitted. For example, with the large flat fins, increasing the suspension cable length from 10 m (33 ft) to 16 m (53 ft) caused a reduction in speed from 95 knot to 65 knot. The bridge had a longitudinal mode of instability when the small fins were fitted, irrespective of cable length, but with the large flat fins, increasing the cable length changed the mode of instability from a longitudinal oscillation to a yaw-lateral oscillation. When the bridge had a high nose down attitude to the flow the longitudinal oscillations always occurred about a rather large trail angle. These high negative angles of attack will lead to large aerodynamic forces being produced and transferred to the helicopter.

For an initial 5° nose down attitude, the bridge fitted with small flat fins became unstable at 55 knot which is 10 knot below the speed achieved with the large fins. Altering the length of the suspension cable did not change the limiting speed or mode of instability and it seems that the small fins do not provide sufficient lateral restraint when the bridge is rigged 5° nose down.

Maximum stability with the small flat fins was achieved when the bridge was slung 5° nose up on a 16 m (53 ft) cable, the limiting speed being 110 knot.

5.1.5 General Comments and Comparison with Other Results for Similar Bridges Fitted with Fins

The current results for the 16 m (52 ft) clear span bridge fitted with flat fins are comparable with results in Table 4, found from model tests of a 15 m (50 ft) decked class 16 airportable bridge, and results in Table 5 for a 16 m (52 ft) full scale bridge carried under a CH54A Skycrane helicopter. The weights, slinging arrangements and dimensions for these three bridges are sufficiently close to one another to make a direct comparison possible. For ease of comparison, the results are summarised together in Table 14.

The full scale results predicted from the current model tests are different from the results predicted from model tests by Sheldon *et al.*[1] in a number of respects. For example, the current results indicated that when the bridge was suspended horizontally on a 10 m (33 ft) cable and fitted with either the large or small flat fins, it would have a longitudinal mode of instability

and the same limiting airspeed. When the bridge was suspended horizontally on longer cables, the mode of instability changed from a yaw-lateral oscillation for the large fins to a lateral oscillation with a very small yaw motion for the small fins, and the limiting speed was reduced by about 10 knot. On the other hand, Sheldon found that large fins produced a longitudinal

TABLE 14

Comparison of Predicted Full Scale Results from Current Model Tests, with Previous Model and Full Scale Test Results for the 16 m (52 ft) Clear Span Bridge[1,2,3].

	Limiting speed (knot)	Mode of instability	Sling height m (ft)	Static incidence (degree)	Fin size
Current model tests	85	longitudinal	10 (33)	0	1·46 m (4·8 ft) chord × 1·22 m (4 ft) high
	90	yaw-lateral	13 (43)	0	,,
	95	yaw-lateral	16 (53)	0	,,
	80	longitudinal	10 (33)	0	1·46 m (4·8 ft) chord × 0·61 m (2 ft) high
	80	lateral	13 (43)	0	,,
	85	lateral-(yaw)	16 (53)	0	,,
	95	longitudinal	10 (33)	+5	1·46 m (4·8 ft) chord × 1·22 m (4 ft) high
	80	yaw-lateral	13 (43)	+5	,,
	65	yaw-lateral	16 (53)	+5	,,
	95	longitudinal	10 (33)	+5	1·46 m (4·8 ft) chord × 0·61 m (2 ft) high
	105	longitudinal	13 (43)	+5	,,
	110	longitudinal	16 (53)	+5	,,
Previous model tests	55	yaw-lateral	4·6 (15)	0	1·07m (3·5ft) chord × 0·89m (2·9ft) high
	80	yaw-lateral	10·7 (35)	0	,,
	90	yaw-lateral	16·8 (55)	0	,,
	75	yaw-lateral	4·6 (15)	+5	,,
	105	yaw-lateral	10·7 (35)	+5	,,
	110	yaw-lateral	16·8 (55)	+5	,,
Full scale tests (CH54A skycrane)	70	High trail angle during manoeuvre	Upper 1·5 (5) Lower 6·1 (20)	0 to +5	1·07m (3·5ft) chord × 0·91m (3·0ft) high
	75	Lateral oscillation	Upper 4·6 (15) Lower 9·2 (30)	0 to +5	,,
	70	Fore-aft swing	Upper 9·2 (30) Lower 9·2 (30)	0 to +5	,,
	60	Poor handling	Upper 1·5 (5) Lower 16·8 (55)	0 to +5	,,

instability, and that small fins produced a yaw-lateral oscillation at a slightly lower limiting airspeed for both short and long cables. Even though the modes of instability predicted from the two sets of tests were sometimes different, the limiting speeds were almost the same when the bridge was suspended horizontally with the same lengths of cable. In both cases higher stable speeds were predicted for longer suspension cables.

When the bridge with the small fins was suspended 5° nose up, the current tests showed that increasing the cable length increased the stable airspeed, which is in agreement with Sheldon's results; but with the large fins there was a significant reduction in stable speed, which is contrary to his results. For the small fins, the limiting speeds predicted from the two sets of model tests were almost identical. On the longer cables, the mode of instability in the present tests changed from a yaw-lateral oscillation with the large fins, to a longitudinal mode with the small fins, which is again opposite to the results of Sheldon[1], where a longitudinal instability was predicted with large fins and a yaw-lateral instability with small fins. On the 10 m (33 ft) cable the current tests predicted a longitudinal mode of instability for both sets of fins, but this mode was only predicted for the large fins by Sheldon.

The current tests indicated the mode of instability of the full scale bridge more accurately than the results of Reference 1. For example, the fore-aft or longitudinal instability which frequently limited the speed of the bridge in practice was more often predicted from the current tests than from Sheldon's *et al.* tests. This was most noticeable when the bridge was fitted with small fins or carried on short cables.

Both series of tests erroneously predicted a yaw-lateral or lateral mode of instability for the bridge fitted with large fins and carried on long cables. However, the current tests also indicated that there would be some concurrent longitudinal motion and that it would damp slowly. If a longitudinal oscillation inadvertently occurred at full scale, for example during a manoeuvre, this might have more effect on the helicopter than anticipated and limit its speed before the lateral or yaw-lateral oscillation has a chance to become significant.

Full scale tests[2] indicated that the size of fins did not have such a great effect on the speed or mode of instability as predicted from previous model tests[1]. The present tests also indicated that the size of the fins was not critical under most conditions, except for a 5° nose up attitude, where size did have a significant effect on the mode of instability and the speed at which it occurred.

Both series of model tests indicated that the speed and mode of instability would be influenced by the initial rigging attitude of the bridge. In the current tests a nose up attitude decreased bridge stability when large fins were fitted, but increased stability when small fins were fitted. Previous model tests had indicated that a nose up attitude increased the stability of the bridge when it was fitted with relatively small fins. However, the effects of bridge incidence are not in agreement with full scale results where small nose up and nose down attitudes were reported to have little effect on the flying qualities of the helicopter[2].

Overall, the results from the current model tests are in better agreement with the full scale results than Sheldon's results, but there are still significant differences between some corresponding conditions. In predicting the behaviour of the full scale bridge from tests on models it has been assumed that the gravitational force is much greater than the viscous force, and the dominating scaling parameter has been taken as the Froude number. However, for long, light, streamlined bodies, such as the 16 m (52 ft) clear span bridge, the ratio of the viscous force to the gravitational force can be relatively large, and errors may occur if the viscous force is not correctly scaled. Sheldon *et al.*[1] obtained their results from tests on a 1/20 scale model, but the current results were obtained from tests with a 1/15 scale model where the viscous forces are scaled more accurately because the Reynolds number is 50% higher. The difference between the behaviour predicted from each size of model also suggests that viscous effects are significant for the 16 m (52 ft) bridge. It is believed that scale effect is the main cause of the difference between the predicted and actual behaviour of the full scale bridge. In addition, the difficulties associated with comparing the mode of instability and the speed at which it occurs, determined from model tests, with full scale trial results where safety is of paramount importance, could also be a contributing factor.

5.1.6 Safe Speed for the Full Scale Bridge

One of the problems in predicting the speed at which the bridge can be safely carried from model tests, is to determine the effect the motion of the bridge has on the helicopter, and to estimate the amplitude of the oscillations which make it difficult to control the helicopter. Of course, if the bridge suddenly becomes unstable, or suffers from very large sustained oscillations, then the airspeed is too high. The effects of various manoeuvres, particularly ascents and descents, can not be directly taken into account in the model tests. The best that can be done is to disturb the model in yaw, and in the lateral and longitudinal directions to try to simulate certain manoeuvres. In addition, there are other effects which have not been directly taken into account in the model tests. For example, no allowance has been made for the destabilising effects which occur when the bridge is not suspended from the centre of gravity of the helicopter. To make an allowance for these unknowns, and to allow some margin for safety, it is estimated that the maximum speed at which the bridge can be carried safely is given by multiplying the speed at which the bridge becomes unstable in Table 13 by a factor of 0·6. This figure of 0·6 is rather arbitrary, but is based on the results from corresponding full scale and model tests in Section 2. The most suitable method of suspension and the maximum speed considered to be safe for carrying the bridge with each type of fin is given in Table 15. The safe speed of 65 knot predicted for the bridge fitted with small flat fins compares favourably with the speed of 50 knot with the V fins, and 40 knot without any fins.

TABLE 15
Most Suitable Method of Suspension and Maximum Safe Speed Predicted for the 16 m (52 ft) Clear Span Bridge.

Configuration	Static orientation	Cable length m (ft)	Safe speed (knot)
Bare bridge—no fins	0° to 5° nose-up	10 m (33 ft) to 16 m (52 ft)	40
Bridge fitted with Vee fins	0° to 5° nose-up	10 m (33 ft)	50
	or		
	0°	13 m (43 ft)	50
Bridge fitted with large flat fins	0°	16 m (53 ft)	55
	or		
	5° nose-up	10 m (33 ft)	55
Bridge fitted with small flat fins	5° nose-up	16 m (53 ft)	65

Even though some margin has been allowed for manoeuvring up to the maximum safe speeds given in Table 15, high lateral and fore and aft accelerations, and fast descents and ascents should be avoided, and the helicopter and load should be manoeuvred carefully at all times, particularly when carrying the bridge near its maximum predicted safe speed. The importance of gentle manoeuvres and restricted speeds is evident from an incident with a similar full scale bridge discussed in Section 2.2.2, where an abrupt descent at a speed of 70 knot caused an excessive oscillation which could not be controlled, and the bridge had to be jettisoned.

5.2 22 m (72 ft) Raft—Load A

Detailed results for load A of the 22 m (72 ft) raft are given in Table 16, and the maximum speed and mode of instability for each configuration are summarized in Table 17.

With a static 5° nose up, or horizontal attitude, the bridge aligned itself with its span in the direction of the vertical flight plane at a speed of about 20 knot, but with a 5° nose down attitude

TABLE 16

Speed and Mode of Instability for Load A of the 22 m (72 ft) Raft Determined from Tests of a 1/15 Scale Model.

α (degree)	Suspension cable length m (ft)	Comments and mode of instability	Maximum stable speed (knot)
0	10 (33)	Load aligned itself with the airflow at low speed and flew 3° nose down at 50 knot. At 70 knot load flew with a 10° nose down attitude and had a small amplitude irregular yaw-lateral-longitudinal oscillation. At 90 knot load flew with 25° nose down attitude, and there was an irregular ±5° longitudinal oscillation combined with a ±5° yaw-lateral oscillation.	90
0	13 (43)	Load aligned itself with the airflow at low speed and flew 2° nose down at 50 knot. At 70 knot load had a 9° nose down attitude and a small amplitude irregular yaw-lateral-longitudinal motion. At 90 knot load had a 20° nose down attitude, with an irregular ±5° longitudinal oscillation combined with a ±4° yaw-lateral oscillation.	90
0	16 (53)	Load aligned itself with airflow at low speed and flew 7° nose down at 70 knot with a small irregular combined yaw-lateral-longitudinal oscillation. At 90 knot load had a 15° nose down attitude with a ±4° longitudinal oscillation combined with a ±3° yaw-lateral oscillation. At 100 knot load had a 21° nose down attitude and a naturally induced divergent lateral oscillation occurred.	95
+5° (nose up)	10 (33)	Load aligned itself with the airflow at low speed and flew 1° nose down at 70 knot with a small amplitude irregular combined yaw-lateral-longitudinal oscillation. At 90 knot load had 10° nose down attitude with a ±2° longitudinal and ±2° lateral oscillation. Input yaw oscillations were sustained. At 95 knot a large random longitudinal-lateral-yaw oscillation developed.	95
+5° (nose up)	13 (43)	Load aligned itself with the airflow at low speed and flew 1° nose down at 70 knot. At 90 knot load had a 7° nose down attitude with a small irregular combined yaw-lateral-longitudinal oscillation. At 100 knot load had a 14° nose down attitude with a random ±5° longitudinal, ±5° yaw, and ±3° lateral oscillation.	100
+5° (nose up)	16 (53)	Load aligned itself with the airflow at low speed and flew level at 70 knot. At 90 knot load had a 4° nose down attitude with a small irregular yaw-lateral-longitudinal oscillation. At 105 knot load had 12° nose down attitude with a sustained ±20° yaw oscillation and a ±3° lateral and ±3° longitudinal oscillation. At 110 knot load had a naturally induced divergent combined yaw-lateral oscillation.	105

TABLE 16.—Continued

α (degree)	Suspension cable length m (ft)	Comments and mode of instability	Maximum stable speed (knot)
−5° (nose down)	10 (33)	Load aligned itself with the airflow at low speed and flew 12° nose down with a slight longitudinal oscillation at 50 knot. At 60 knot load had a 15° nose down attitude with a ±3° longitudinal, ±3° yaw, and ±2° lateral motion which increased to 24° nose down and a ±4° longitudinal, ±6° yaw and ±3° lateral motion at 70 knot. At 75 knot load had a naturally induced divergent yaw-lateral oscillation.	70
−5° (nose down)	13 (43)	Load aligned itself with the airflow at low speed and flew 10° nose down with a slight erratic motion at 50 knot. At 60 knot load had 13° nose down attitude with ±2° longitudinal, ±3° yaw, and ±2° lateral motion which increased to a 20° nose down attitude and ±3° longitudinal, ±5° yaw, and ±4° lateral motion at 70 knot. At 80 knot load had a 26° nose down attitude, and a yaw induced naturally divergent lateral oscillation developed.	75
−5° (nose down)	16 (43)	Load aligned itself with the airflow at low speed and flew 10° nose down at 50 knot. At 70 knot load had a sustained ±3° longitudinal, ±5° yaw, and ±4° lateral oscillation. At 80 knot load had approximately 25° nose down attitude and a naturally induced lateral oscillation developed.	75

TABLE 17

Summary of Speed and Mode of Instability Predicted for Load A of the 22 m (72 ft) Raft.

α (degree)	Suspension cable length m (ft)	Maximum stable speed (knot)	Mode of instability
0	10 (33)	90	longitudinal-erratic
	13 (43)	90	longitudinal-erratic
	16 (53)	95	lateral
+5° (nose up)	10 (33)	95	errati· longitudinal-lateral-yaw motion
	13 (43)	100	longitudinal-erratic
	16 (53)	105	yaw-lateral
−5° (nose down)	10 (33)	70	yaw-lateral
	13 (43)	75	lateral
	16 (53)	75	lateral

alignment occurred at about 15 knot. The bridge usually took a long time to line up with the airflow, and it often flew in a stable position with up to $\pm 50°$ yaw at low speed. As the speed increased, a low frequency yaw oscillation often occurred but quickly reduced in amplitude at higher speeds. Placing the accessories on the aft section of the bridge appears to be a satisfactory method for aligning it with the airflow at relatively low speeds and is comparable with the use of fins on the 16 m (52 ft) clear span bridge.

When the bridge was rigged horizontally or 5° nose up on the 10 m (33 ft) or 13 m (43 ft) long cables its speed was limited by a high nose down attitude and an irregular combined longitudinal-lateral-yaw oscillation which was relatively large in amplitude but not divergent. The high nose down attitude of up to 25°, coupled with the oscillation of the load, would produce large static and fluctuating forces on the helicopter and prevent higher speeds from being attained.

When the bridge was suspended either horizontally or 5° nose up on the 16 m (53 ft) cable, or 5° nose down on the 10 m (33 ft), 13 m (43 ft) or 16 m (53 ft) cables, its speed was limited by a naturally divergent lateral or yaw-lateral oscillation. The lateral instability was always accompanied by a small yaw oscillation of approximately $\pm 5°$.

An improvement in airspeed of 5 to 10 knot was achieved by slinging the bridge 5° nose up instead of horizontally, but with a 5° nose down attitude, the speed was reduced by about 20 knot compared with a horizontal position.

Changing the length of the suspension cable from 10 m (33 ft) to 16 m (53 ft) increased the stable airspeed by 5 to 10 knot for a static attitude between 5° nose up, and 5° nose down. This is in agreement with previous wind tunnel predictions discussed in Section 2.2.3, but is contrary to some of the results for the 16 m (52 ft) clear span bridge fitted with either V fins or large flat fins where higher speeds were achieved with shorter cables. When load A was suspended on the 10 m (33 ft) cable its speed was usually limited by a longitudinal or irregular type of oscillation, but on the longer 16 m (53 ft) cable the speed was limited by a yaw-lateral or lateral mode of oscillation. Similar longitudinal and yaw-lateral modes of instability had been found previously for the clear span bridge on short and long cables respectively.

In all cases a strong manual disturbance could induce the bridge to become unstable at about 5 to 10 knot below the speed at which it became unstable naturally. Manually induced longitudinal oscillations damped very slowly, and if these occur in practice, for example when manoeuvring, then handling problems may result near the limiting speeds.

No tests were carried out with other stabilising devices, such as fins, fitted to the bridge because it was considered that the maximum speeds already achieved were high enough for present purposes.

From the tests, the best method of carrying the bridge is to rig it 1° to 2° nose up on a 16 m (52 ft) cable, where its maximum speed before becoming unstable is 100 knot. However, the bridge cannot be safely carried at 100 knot. The maximum safe speed at which the bridge can be carried is estimated to be 60 knot. This is determined by multiplying the maximum stable speed by a factor of 0·6, the same factor used in Section 5.1.6 for the 16 m (52 ft) clear span bridge, to allow for various effects of the motion of the load not simulated in the model tests, together with some margin for safety.

5.3 22 m (72 ft) Raft—Load B

The results for load B of the 22 m (72 ft) raft are given in detail in Table 18, and the maximum speed and mode of instability for each configuration are summarised in Table 19. This load is 9·8 m (32 ft) long and is a shortened version of the 16 m (52 ft) clear span bridge. Both bridges have the same width and height and the same ramps are fitted at each end. Load B is dimensionally similar to the 9 m (28 ft) and 11 m (36 ft) class 16 airportable bridges listed in Table 1, but the static weight of load B is more than twice the static weight of the 9 m (28 ft) and the 11 m (36 ft) bridges. Because weight has a significant influence on stability[8], it is difficult to compare the speeds and modes of instability determined from previous tests of these bridges with the results for load B given in this section.

TABLE 18

Speed and Mode of Instability for Load B of the 22 m (72 ft) Raft Determined from Tests of a 1/15 Scale Model.

(a) Load without Fins.

α (degree)	Suspension cable length m (ft)	Comments and mode of instability	Maximum stable speed (knot)
0	10 (33)	Bridge yawed to broadside position at approximately 15 knot with a large amplitude low frequency yaw oscillation of $\pm 20°$ which decreased in amplitude as speed increased. At 70 knot load had a 7° leading edge down incidence to the flow, and at 80 knot a naturally induced divergent lateral-longitudinal oscillation occurred.	75
0	13 (43)	Same as for $\alpha = 0°$ and suspension cable length = 10 m (33 ft): except divergent yaw-lateral-longitudinal oscillation occurred.	75
0	16 (53)	Same as for $\alpha = 0°$ and suspension cable length = 10 m (33 ft), except divergent yaw-lateral oscillation occurred at 85 knot.	80
+5 (nose up)	10 (33)	Bridge yawed to broadside position at approximately 10 to 15 knot, slight yaw-lateral motion. At 60 knot load became unstable with a combined yaw-lateral-longitudinal oscillation.	55
+5 (nose up)	13 (43)	Bridge yawed to broadside position at approximately 10 knot with slight yaw-lateral motion. Divergent yaw oscillation at 75 knot—load turned end for end—combined with longitudinal oscillations.	70
+5 (nose up)	16 (53)	Bridge yawed to broadside position at approximately 10 to 15 knot, with slight yaw-lateral motion. At 75 knot load had a naturally induced divergent yaw-lateral-longitudinal oscillation.	70
−5 (nose down)	10 (33)	Bridge remained aligned with airflow. At 50 knot there was a sustained $\pm 10°$ yaw oscillation. At 55 knot load experienced a naturally induced divergent yaw-lateral oscillation with some longitudinal motion.	50
−5 (nose down)	13 (43)	Bridge remained aligned with airflow. At 55 knot load experienced a naturally induced divergent lateral oscillation with sustained $\pm 10°$ yaw.	50
−5 (nose down)	16 (53)	Bridge remained aligned with airflow. Sustained $\pm 10°$ yaw oscillation at 50 knot. Naturally induced divergent lateral oscillation with sustained $\pm 15°$ yaw at 55 knot.	50

TABLE 18.—Continued

(b) Load Fitted with V Fins

α (degree)	Suspension cable length m (ft)	Comments and mode of instability	Maximum stable speed (knot)
NOTE: 1. Load always became aligned with the airflow at speeds above approximately 10 to 15 knot. 2. Yaw oscillations always occurred about a vertical axis at the aft end of the load and about midway between the two fins. 3. Small longitudinal oscillations of $\pm 1°$ to $\pm 2°$ always existed above about 20 knot, and manually induced longitudinal oscillations damped slowly.			
0	10 (33)	Load remained stable up to 50 knot. At 55 knot manual disturbance damped slowly. At 60 knot an initial self excited yaw oscillation led to a divergent yaw-lateral oscillation.	55
0	13 (43)	Load remained stable up to 45 knot. At 50 knot there was a sustained yaw oscillation of $\pm 10°$, and at 55 knot a naturally induced divergent yaw-lateral oscillation occurred.	50
0	16 (53)	Load remained stable up to 40 knot. At 45 knot there was a sustained yaw oscillation of $\pm 5°$, and at 50 knot a naturally induced slowly divergent yaw-lateral oscillation occurred.	45
+5 (nose up)	10 (33)	Load remained stable up to 45 knot. At 50 knot a small input disturbance induced a sustained $\pm 5°$ yaw oscillation. At 55 knot a naturally induced yaw-lateral oscillation developed.	50
+5 (nose up)	13 (43)	Load remained stable up to 40 knot. At 45 knot there was a sustained $\pm 5°$ yaw oscillation, and at 50 knot load had a naturally induced divergent yaw-lateral oscillation.	45
+5 (nose up)	16 (53)	Results are the same as for $\alpha = +5°$ and 13 m (43 ft) suspension cable.	45
−5 (nose down)	10 (33)	Load remained stable up to 50 knot. At 55 knot there was a sustained $\pm 5°$ yaw oscillation, and at 60 knot load had a naturally induced divergent yaw-lateral oscillation.	55
−5 (nose down)	13 (43)	Load remained stable up to 45 knot. At 50 knot there was a sustained $\pm 5°$ yaw oscillation, and at 55 knot load had a naturally induced divergent yaw-lateral oscillation.	50
−5 (nose down)	16 (53)	Load remained stable up to 40 knot. At 45 knot there was a sustained $\pm 5°$ yaw oscillation, and at 50 knot load had a naturally induced divergent yaw-lateral oscillation.	45

TABLE 18.—Continued

(c) Load Fitted with Large Flat Fins.

α (degree)	Suspension cable length m (ft)	Comments and mode of instability	Maximum stable speed (knot)
NOTE: 1. Load always became aligned with the airflow at speeds above approximately 10 to 15 knot. 2. Yaw oscillations always occurred about a vertical axis at the aft end of the load and approximately midway between the two fins. 3. Small longitudinal oscillations of $\pm 1°$ to $\pm 2°$ always existed above 30 knot, and manually induced longitudinal oscillations damped slowly.			
0	10 (33)	Load remained stable up to 50 knot. At 60 knot a large manual disturbance led to a small sustained yaw oscillation. At 70 knot a naturally induced yaw oscillation produced a divergent lateral oscillation.	65
0	13 (43)	Load remained stable up to 50 knot where a manual disturbance led to a sustained yaw oscillation. At 60 knot load experienced a natural yaw induced slowly divergent lateral oscillation.	55
0	16 (53)	Load remained stable up to 40 knot. At 45 knot a manual disturbance led to a small sustained yaw oscillation. At 50 knot a small input disturbance induced a slowly divergent lateral oscillation with $\pm 10°$ yaw.	45
+5 (nose up)	10 (33)	Load remained stable up to 50 knot. At 55 knot a manual disturbance led to a small sustained yaw oscillation. At 60 knot load experienced a naturally occurring yaw-induced divergent lateral oscillation.	55
+5 (nose up)	13 (43)	Load remained stable up to 40 knot. At 45 knot a manual disturbance led to a small sustained yaw oscillation. At 50 knot a small naturally induced yaw oscillation led to a divergent lateral oscillation.	45
+5 (nose up)	16 (53)	Results are same as for $\alpha = 5°$ and 13 m (43 ft) suspension cable.	45
−5 (nose down)	10 (33)	Load remained stable up to 60 knot. At 65 knot a manual disturbance led to a small sustained yaw-lateral oscillation. At 70 knot a naturally induced divergent yaw-lateral oscillation occurred.	65
−5 (nose down)	13 (43)	Load remained stable up to 50 knot. At 55 knot a manual disturbance led to a small sustained yaw-lateral oscillation. At 60 knot a manual disturbance led to a divergent yaw-lateral oscillation.	55
−5 (nose down)	16 (53)	Load remained stable up to 45 knot. At 50 knot a manual disturbance led to a small sustained yaw oscillation. At 55 knot load had a naturally induced divergent yaw-lateral oscillation.	50

TABLE 18.—Continued

(d) Load Fitted with Small Flat Fins.

α (degree)	Suspension cable length m (ft)	Comments and mode of instability	Maximum stable speed (knot)
NOTE: 1. Load always became aligned with the airflow at speeds above about 15 knot. 2. Yaw oscillations always occurred about a vertical axis located approximately two bridge lengths aft of the fins, and midway between the two fins. 3. Small longitudinal oscillations of $\pm 1°$ to $\pm 2°$ always existed above 40 knot, and manually induced longitudinal oscillations damped slowly.			
0	10 (33)	Load remained stable up to 80 knot and had 9° nose down attitude at 70 knot. At 85 knot load had 15° nose down attitude and a sustained $\pm 10°$ yaw oscillation existed. At 90 knot a naturally induced yaw-lateral oscillation occurred.	85
0	13 (43)	Results are the same as for $\alpha = 0°$ and 10 m (33 ft) long suspension cable.	85
0	16 (53)	Results are the same as for $\alpha = 0°$ and 10 m (33 ft) long suspension cable.	85
+5 (nose up)	10 (33)	Load had a horizontal attitude at 80 knot, and remained stable up to 90 knot. At 100 knot load had 4° nose down attitude and a very small manual disturbance led to a sustained yaw oscillation. At 105 knot load had a naturally induced divergent lateral oscillation.	100
+5 (nose up)	13 (43)	Load had a 2° nose down attitude at 80 knot, and remained stable up to 80 knot. At 85 knot a manual disturbance damped slowly. At 95 knot a manual disturbance induced a divergent lateral oscillation with a small yaw oscillation.	90
+5 (nose up)	16 (53)	Load remained stable up to 70 knot. At 75 knot a manual disturbance led to a sustained lateral oscillation. At 80 knot a manual disturbance induced a divergent lateral oscillation with a small yaw oscillation.	75
−5 (nose down)	10 (33)	Load had 10° nose down attitude at 60 knot, and remained stable up to 60 knot. At 65 knot a manual disturbance led to a small sustained yaw oscillation. At 70 knot a naturally induced divergent lateral oscillation occurred with a small yaw oscillation.	65
−5 (nose down)	13 (43)	Load had 13° nose down attitude at 70 knot with a small sustained yaw oscillation. At 75 knot load had a 20° nose down attitude and a naturally induced divergent yaw-lateral oscillation occurred.	70
−5 (nose down)	16 (53)	Results the same as for $\alpha = -5°$ and 13 m (43 ft) long suspension cable, except load had 18° nose down attitude at 75 knot.	70

TABLE 19

Summary of Speed and Mode of Instability Predicted for Load B of the 22 m (72 ft) Raft.

α (degree)	Suspension cable length m (ft)	Speed (knot) and mode of instability			
		No fins	V fins	Large flat fins	Small flat fins
0	10 (33)	75 lateral-longitudinal	55 yaw-lateral	65 lateral-(yaw)	85 lateral
	13 (43)	75 yaw-lateral-longitudinal	50 yaw-lateral	55 lateral-(yaw)	85 lateral
	16 (53)	80 yaw-lateral	45 yaw-lateral	45 lateral-(yaw)	85 lateral
+5 (nose up)	10 (33)	55 yaw-lateral-longitudinal	50 yaw-lateral	55 lateral-(yaw)	100 lateral
	13 (43)	70 yaw-(longitudinal)	45 yaw-lateral	45 lateral-(yaw)	90 lateral-(yaw)
	16 (53)	70 yaw-lateral-longitudinal	45 yaw-lateral	45 lateral-(yaw)	75 lateral-(yaw)
−5 (nose down)	10 (33)	50 yaw-lateral-longitudinal	55 yaw-lateral	65 law-yateral	65 lateral-(yaw)
	13 (43)	50 lateral-(yaw)	50 yaw-lateral	55 yaw-lateral	70 lateral-(yaw)
	16 (53)	50 lateral-(yaw)	45 yaw-lateral	50 yaw-lateral	70 lateral-(yaw)

5.3.1 Load B without Fins

With a static 5° nose up or horizontal attitude, the load turned broadside at low speed where small irregular yaw oscillations usually occurred. As the speed was increased above approximately 20 knot the load became 'stable' in a broadside orientation and relatively high speeds could be achieved before it became unstable. However, this orientation would induce large drag and negative lift forces on the load which would be transferred to the helicopter. When the load was slung with an initial 5° nose down attitude it's longitudinal axis became aligned with the vertical flight plane. Similar effects were found previously with the 16 m (52 ft) clear span bridge.

When the load was suspended horizontally the maximum speed achieved before it became naturally unstable was approximately 80 knot, but when it was suspended 5° nose down the limiting speed was reduced to 50 knot. Changing the length of the suspension cable from 10 m (33 ft) to 16 m (53 ft) did not alter the limiting speed in either case, but the mode of instability changed slightly as the cable was increased in length. With an initial horizontal attitude, the mode changed from a lateral-longitudinal oscillation with very little yaw for the short 10 m (33 ft) cable, to a yaw-lateral-longitudinal oscillation with the 13 m (43 ft) cable, and then to a yaw-lateral oscillation without any significant longitudinal motion on the longer 16 m (53 ft) cable. At 5° nose down, the instability altered from a yaw-lateral-longitudinal mode on the short cable to a lateral mode with approximately $\pm 10°$ yaw on the longer cables.

With the load statically suspended 5° nose up, increasing the length of the suspension cable from 10 m (33 ft) to 13 m (43 ft) increased the maximum stable speed from 55 to 70 knot, but a further increase in cable length to 16 m (53 ft) did not alter the speed. It was found that an external disturbance at high speed could cause the load to suddenly yaw a further 90° to finish end for end with a high nose down attitude where either a large amplitude longitudinal oscillation was produced or a sling leg failed.

From the results, the most suitable method of carrying the load is to rig it horizontally, on a 16 m (53 ft) long cable where its speed is limited to 85 knot by a yaw-lateral oscillation.

5.3.2 Load B Fitted with V Fins

The V fins aligned the longitudinal axis of the load with the vertical flight plane at a speed of about 10 knot as in the case of the 16 m (52 ft) bridge.

When the load was rigged either horizontally or 5° nose down on a 10 m (33 ft) suspension cable it became naturally unstable in a yaw-lateral mode at 55 knot. If the load was suspended 5° nose up the stable speed was reduced to 50 knot. Changing the length of the cable from 10 m (33 ft) to 16 m (53 ft) reduced the stable speed to 45 knot when the load was suspended either horizontally, 5° nose up, or 5° nose down. Similar effects were found previously for changes in cable length when V fins were fitted to the 16 m (52 ft) bridge.

In all cases, the speed was limited by a combined yaw-lateral mode of oscillation. The yaw oscillations always occurred about a vertical axis located midway between the fins at the aft end of the load. A very small longitudinal movement usually occurred above about 20 knot, but the load did not experience any unstable longitudinal oscillations. The mode of instability for both load B and the 16 m (52 ft) bridge was the same when they were carried on 13 m (43 ft) and 16 m (53 ft) cables, but on the shorter 10 m (33 ft) cable the bridge developed a longitudinal mode of instability while load B retained a yaw-lateral mode of instability.

The maximum speeds achieved with V fins fitted to the load were all well below the stable speeds without fins. This is contrary to the results for the 16 m (52 ft) bridge where the V fins increased the stable speed by between 5 and 20 knot depending on the static orientation and the length of suspension cable.

Fitting V fins to this load is therefore not an appropriate solution for increasing its stability, in fact, they have a detrimental effect on stability.

5.3.3 Load B Fitted with Large Flat Fins

The results obtained with the large flat fins were very similar to the results for the load with the V fins. However, the stable airspeed was 5 knot greater with the flat fins, and they produced a divergent lateral oscillation with only a small amount of yaw instead of a combined yaw-lateral mode of instability.

The maximum speeds achieved with the large flat fins were again well below the speeds without fins and therefore they are not satisfactory for this load.

5.3.4 Load B Fitted with Small Flat Fins

These fins did not make the load as directionally stable at low speeds as the large flat fins, and rather large yaw oscillations occurred below 10 knot before the load eventually became aligned with the airflow at about 20 knot.

Contrary to the previous two cases, the limiting speeds for the load with the small flat fins were higher than without any fins. With the load suspended horizontally on cables between 10 m (33 ft) and 16 m (53 ft) in length, the speed was limited to 85 knot by a lateral oscillation without any significant yaw motion. With an initial 5° nose up attitude and a 10 m (33 ft) cable the speed was limited to 100 knot by a pure lateral mode of instability, but as the cable was increased in length the speed was reduced, and on the 16 m (53 ft) cable it was limited to 75 knot by a lateral oscillation coupled with a small yaw motion. When the load was suspended 5° nose down, its speed was limited to 65 knot on a 10 m (33 ft) cable and 70 knot on a 16 m (53 ft) cable by a lateral oscillation coupled with a small yaw oscillation. The yaw oscillation always

occurred about a vertical axis located approximately midway between the fins and about two lengths of the load aft of the fins.

In all cases a manual disturbance could induce the load to become unstable at a speed of about 5 knot below the speed at which it became unstable naturally. Manually induced longitudinal oscillations always damped very slowly, and above about 40 knot a small sustained longitudinal oscillation always existed.

The most suitable method of carrying the load fitted with the small flat fins is to rig it 5° nose up on a 10 m (33 ft) cable where its speed is limited to 100 knot by a divergent lateral oscillation.

5.3.5 General Comments and Predicted Safe Speed for Full Scale Load B

Following the same line of reasoning used in Section 5.1.6 for the 16 m (52 ft) clear span bridge the maximum speed at which load B can be safely carried by a helicopter is obtained by multiplying the speed at which the load becomes unstable in Table 19 by a factor of 0·6. The most suitable method of suspension and the estimated maximum safe speed for carrying the load with each type of fin is given in Table 20. Even though some margin has been allowed for manoeuvring up to the maximum predicted safe speeds, the helicopter and load should always be manoeuvred carefully especially when carrying the bridge near its maximum predicted safe speed.

TABLE 20

Most Suitable Method of Suspension and Maximum Safe Speed Predicted for Load B of the 22 m (72 ft) Raft.

Configuration	Static orientation	Cable length m (ft)	Safe speed (knot)
Bare load—no fins	0°	16 m (53 ft)	50
Load fitted with V fins	0° to 5° nose down	10 m (33 ft)	35
Load fitted with large flat fins	0° to 5° nose down	10 m (33 ft)	40
Load fitted with small flat fins	5 nose up	10 m (33 ft)	60

The results in Table 20 indicate that the small fins produce the most stable helicopter-load configuration and allow the load to be transported at the highest speed. Neither the large flat fins nor the V fins are suitable for this load. In both cases, large yaw oscillations occurred about the tail of the bridge at low speed, and this caused high lateral loads to be produced which forced the bridge into a combined yaw-lateral mode of instability. With the small fins, high yaw angles were not produced and consequently high lateral forces were not generated, and the load remained stable at higher speeds.

Longitudinal oscillations always occurred above about 20 knot with any of the fins but were quite small in amplitude and did not limit speed. Relatively large amplitude manually induced longitudinal oscillations damped very slowly especially at higher speeds. If produced inadvertently at full scale by unnecessarily sharp manoeuvres they might cause stability problems. Care must therefore be exercised in handling the helicopter to avoid their excitation.

Without fins the load always turned broadside at low speed and remained stable up to a relatively high speed when a high 'leading edge down' attitude occurred with a large trail angle and the load became unstable with a combined yaw-lateral-longitudinal oscillation. Fitting any of the fins forced the load to fly with its axis in the direction of the vertical flight plane at relatively

high speed where large aerodynamic forces would not be produced and transferred to the helicopter.

Overall, the large flat fins and the V fins were found to be detrimental to the stability of the load and they should not be used. If necessary, the load can be carried safely without fins at speeds up to 50 knot, but it will turn broadside where large drag and negative lift forces will be produced. Small flat fins fitted to the load will cause it to streamline with a consequent reduction in aerodynamic forces and it can be carried safely at 60 knot.

6. CONCLUSIONS

The following conclusions are drawn from reviewing existing information on carrying bridges beneath helicopters and from the current wind tunnel tests of class 16 airportable bridge models.

1. It is feasible to carry an airportable bridge on a sling beneath a helicopter, provided the weight and rotor downwash load is within its lifting capacity, and provided its speed and manoeuvring ability are restricted sufficiently to prevent load oscillations from causing control difficulties.
2. Testing dynamically similar models is a simple and effective method for identifying the type of load instability and the limiting speed of the helicopter, without the safety and physical restrictions imposed by full scale tests.
3. Froude number is the dominant scaling parameter for practical model tests of bridges but viscous effects can be important, and the models must be tested at a sufficiently high Reynolds number for the limiting speed and mode of instability of the full size bridge to be predicted accurately.
4. The speed at which a bridge can be safely carried on a routine mission must be considerably lower than the speed at which it becomes unstable in order to allow for manoeuvring and unforeseen effects.
5. Full scale flight trials should be carried out to verify the predicted safe flying conditions before any bridge is carried on routine missions.
6. When the bridge is carried at high speed or during manoeuvres, forces on the suspension hook of up to three times the static weight can be produced, and it is advisable to provide some means for indicating the load on the hook to the pilot for monitoring so that he can prevent the helicopter from becoming overloaded inadvertently.
7. The vertical drag on the bridge caused by the downwash of the rotor can result in a serious loss of nett thrust in hover and low forward speed flight, and must be allowed for when planning a mission.
8. Cable length generally has little effect on stability, although pilots usually consider flying qualities are slightly better with shorter cables.
9. Fins are suitable for increasing the stability of bridges and for aligning the span with the vertical flight plane where aerodynamic forces are minimised, but care must be exercised in their design. If the fins are too large stability may be reduced, and if they are too small the bridge will not align with the airflow.
10. Longitudinal bridge oscillations damp very slowly and are particularly disturbing to the helicopter. They can result in severe handling problems particularly if inadvertently excited, for example, during manoeuvres.
11. To maximise load stability the helicopter should be manoeuvred cautiously at all times.
12. A horizontal or slight nose up static attitude for the bridge gives greater stability than a nose down attitude.
13. *16 m (52 ft) class 16 clear span bridge.*
    (a) Without fins, and with a static horizontal or 5° nose up attitude, the bridge flew broadside where a longitudinal oscillation limited the airspeed. With a 5° nose down attitude the bridge remained aligned with the airstream, and its speed was limited by a yaw-lateral oscillation. A maximum safe speed of 40 knot was predicted for cable lengths between 10 m (33 ft) and 16 m (52 ft) and static 5° nose up or horizontal attitudes.

(b) With fins, a longitudinal mode of instability limited the speed of the bridge when it was carried on a 10 m (33 ft) cable, but on the longer 13 m (43 ft) and 16 m (53 ft) slings its speed was limited by a lateral or yaw-lateral oscillation.

(c) All three sets of fins improved stability and allowed the bridge to be carried safely at higher speeds than without fins. A maximum safe speed of 65 knot was estimated when the bridge was fitted with the small flat fins and suspended 5° nose up on the 10 m (53 ft) cable.

14. 22 m (72 ft) raft—load A.

(a) Load A was slow to align with the airflow, and below 20 knot it often flew in a stable position with up to 50° yaw.

(b) When the load was suspended either horizontally or 5° nose up on the short 10 m (33 ft) cable the speed was limited by a high trail angle combined with an irregular longitudinal-lateral-yaw oscillation, but with a 5° nose down attitude or longer cables the speed was limited by a lateral or yaw-lateral oscillation.

(c) Placing the accessories on the aft section of the load is a suitable method for aligning it with the airflow and for obtaining a sufficiently high airspeed without using other stabilizing devices.

(d) The best method for carrying load A is to rig it 1° to 2° nose up on a 16 m (53 ft) cable where its safe speed was estimated to be 60 knot.

15. 22 m (72 ft) raft—load B.

(a) Without fins, and with an initial horizontal, 5° nose up, or 5° nose down attitude on the 10 m (33 ft) cable the load flew broadside and its speed was limited by a yaw-lateral-longitudinal oscillation. On the longer 16 m (53 ft) cable the speed was limited by a lateral or a combined yaw-lateral oscillation. The maximum safe speed was estimated to be 50 knot provided the load is suspended horizontally on a 16 m (53 ft) cable.

(b) Both the V fins and the large flat fins aligned the load with the airflow, but they made it far less stable than in the broadside position and a yaw lateral oscillation limited its speed to a much lower value than without fins.

(c) Small flat fins aligned the bridge with the airflow at low speeds and increased the stability compared with the bridge without fins. The speed was limited by a lateral oscillation.

(d) The maximum safe speed at which the bridge could be carried was 60 knot, and this was predicted to occur when it was fitted with the small flat fins, statically suspended 5° nose up, and carried on the 10 m (33 ft) cable.

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